

Revised View of Solar X-Ray Jets

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Introduction: Solar X-Ray Jets

- ♦ Observed since the Yohkoh days (Shibata et al. 1992; also Shimojo et al. 1996, etc.)
- ♦ Yohkoh (SXT) saw them mainly in active regions.
- ♦ Hinode/XRT found them to be plentiful in polar coronal holes (Cirtain et al. 2007; also Savcheva et al. 2007, etc.)
- ♦ In polar coronal holes: size $\sim 50,000$ km x 8000 km; rate ~ 60 /day (Savcheva et al. 2007).
- ♦ Often have a “hot loop” at the jet’s base.

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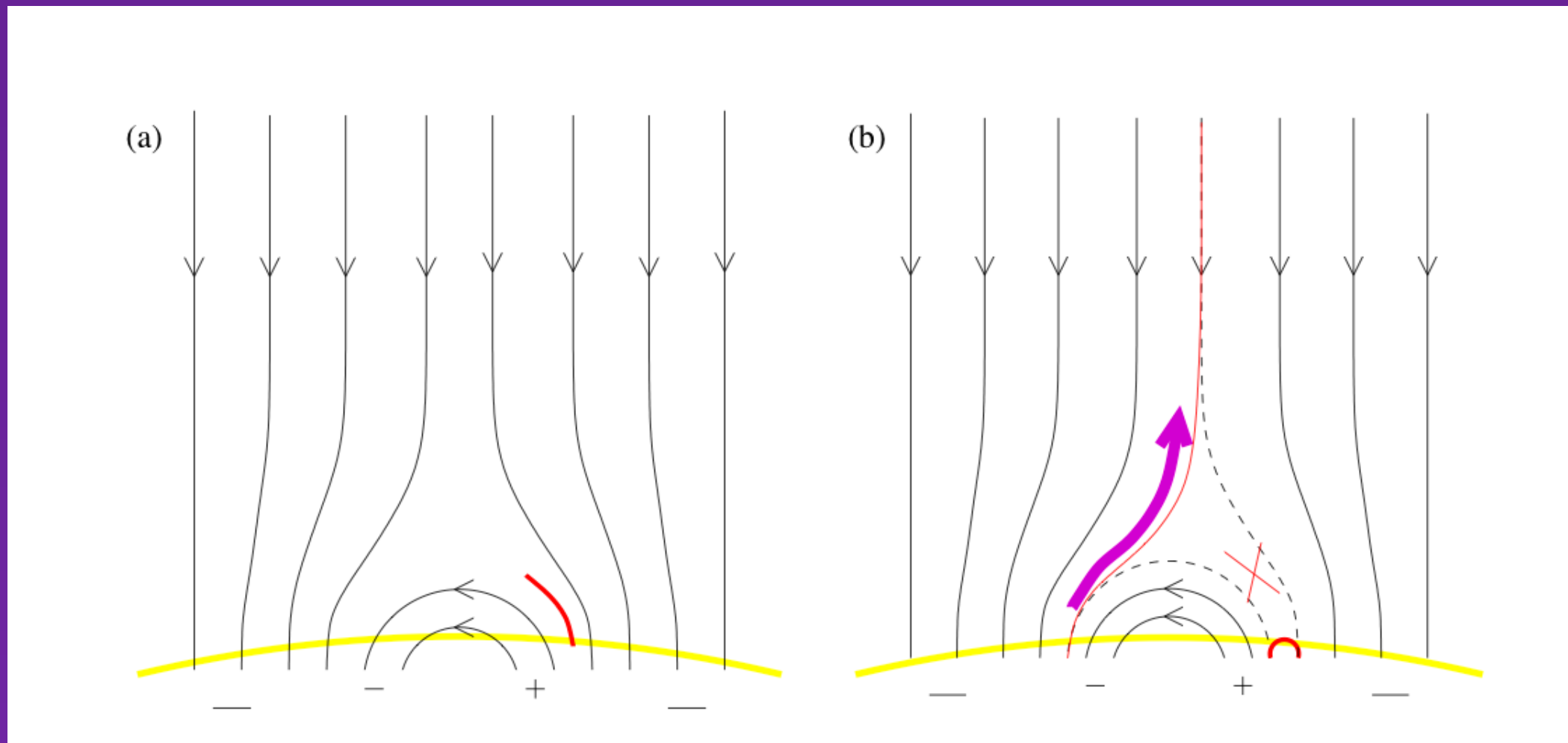
Often-discussed mechanism is based on emerging flux (“emerging-flux model”). (Shibata et al. 1992; see also Moore et al. 2010.)

Many of the above observations and mechanism ideas were largely deduced from SXR, and specifically from pre-SDO AIA observations.

Next: An overview of the emerging flux idea.

Later: Observations of (X-ray) jets using AIA, and resulting implications for the emerging-flux mechanism.

Emerging-Flux Model for (X-Ray) Jets



Supported by numerical simulations: Yokoyama & Shibata (1995), Nishizuka et al. (2008), Archontis et al. (2013), Moreno-Insertis et al. (2013), Fang et al. (2014), etc.

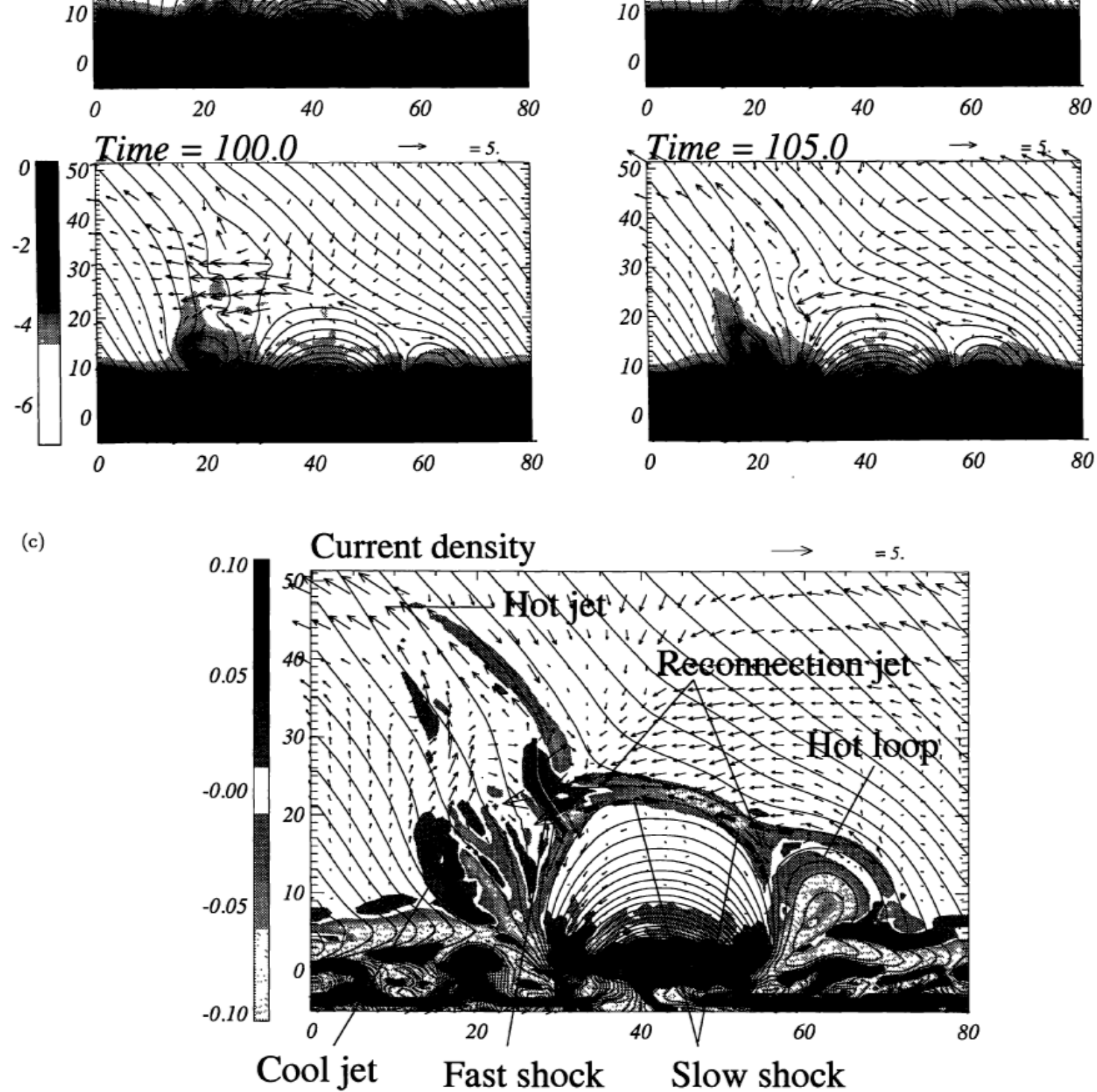


Fig. 9. Simulation results of the typical model (model 7) for the oblique-coronal-field case, $\theta_{\text{cor}} = 3\pi/4$. The figure shows the region near to the central loops (lower half of the computation box), whose range is $0 \leq x \leq 80$ and $-5 \leq z \leq 50$. Panels (a) and (b) show the time evolution of the temperature T , and the density $\log_{10} \rho$, respectively. Panel (c) shows the current density J_y distribution at $t = 105.0$. The remaining notation is the same as in figure 3. (See Plate 9 for figure 9a.)

Standard Jets and Blowout Jets

- ✧ X-ray Jets, from the time of Yohkoh: E.g., Shibata et al. (1992); Shimojo et al. (1996); and Hinode, e.g., Cirtain et al. (2007).
- ✧ Jet model, later known as “standard jets”:
 - ✧ Shibata et al.
 - ✧ Yokoyama & Shibata (1995, 1996)
 - ✧ Moreno-Insertis et al. (2008)
 - ✧ Archontis & Hood (2013)....
- ✧ Dichotomy: Standard and Blowout Jets
 - ✧ Moore et al. (2010)
 - ✧ Moore et al. (2013)
 - ✧ Blowout jets seen by several workers (Liu et al. 2011, Standard to Blowout; Hong et al. 2011, Shen et al. 2012, CMEs with blowout jets; Moreton et al 2012; etc.)

Standard vs. Blowout

(Moore et al. 2010, 2013)

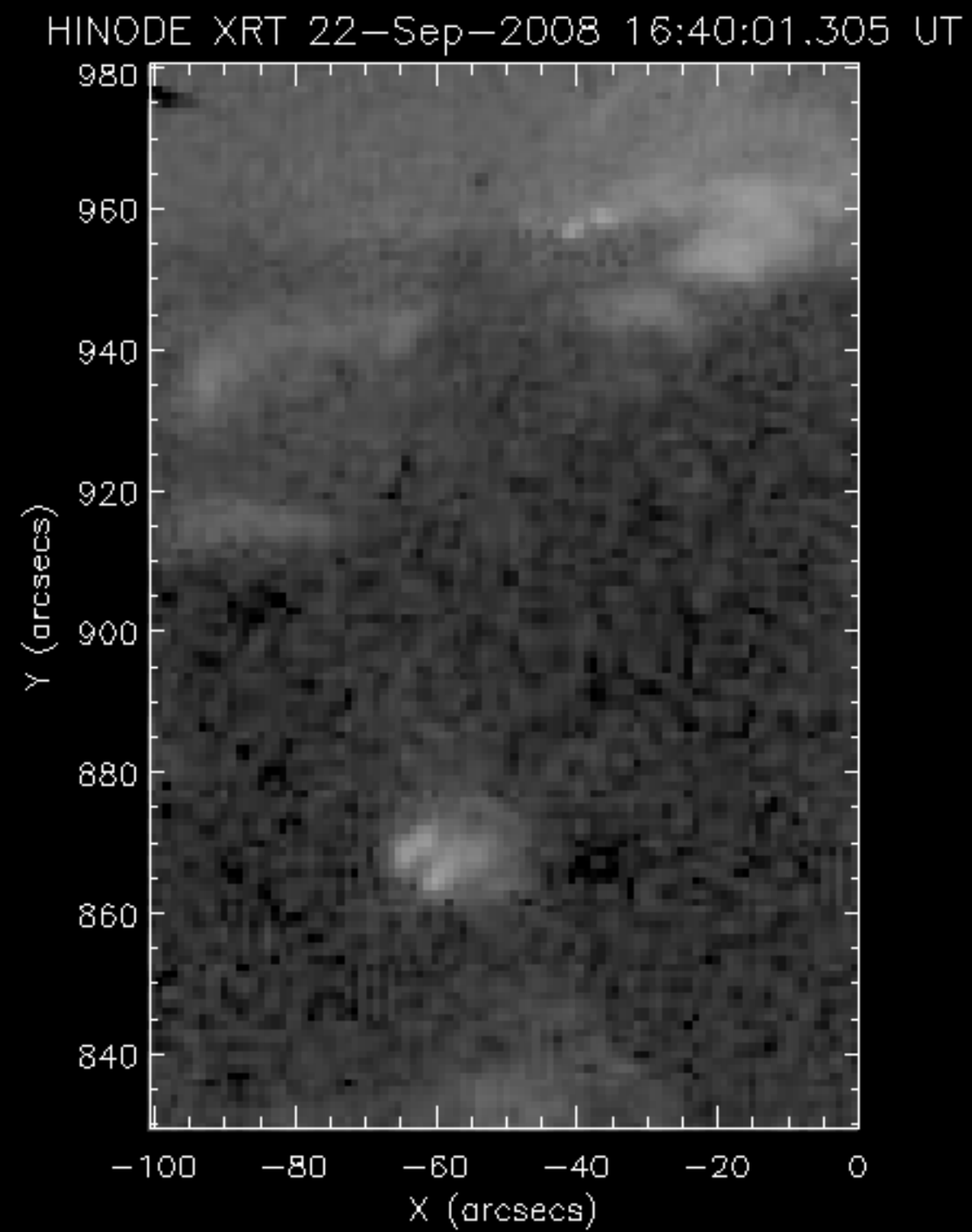
🔦 Standard:

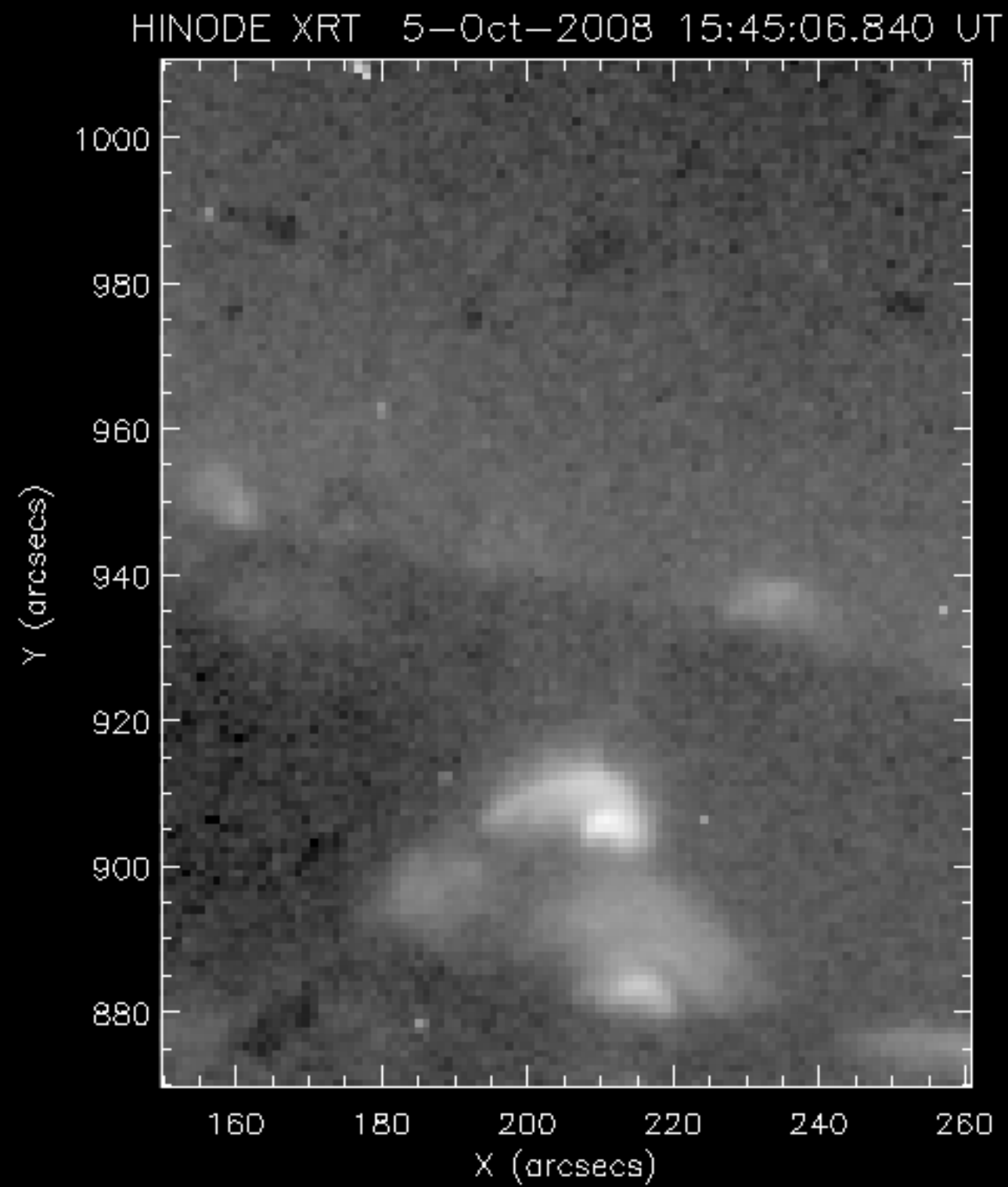
- 🔦 Simple ("single") spire
- 🔦 Little X-ray brightening at base, cf. bright point
- 🔦 Little or no emission in cooler lines.

🔦 Blowout:

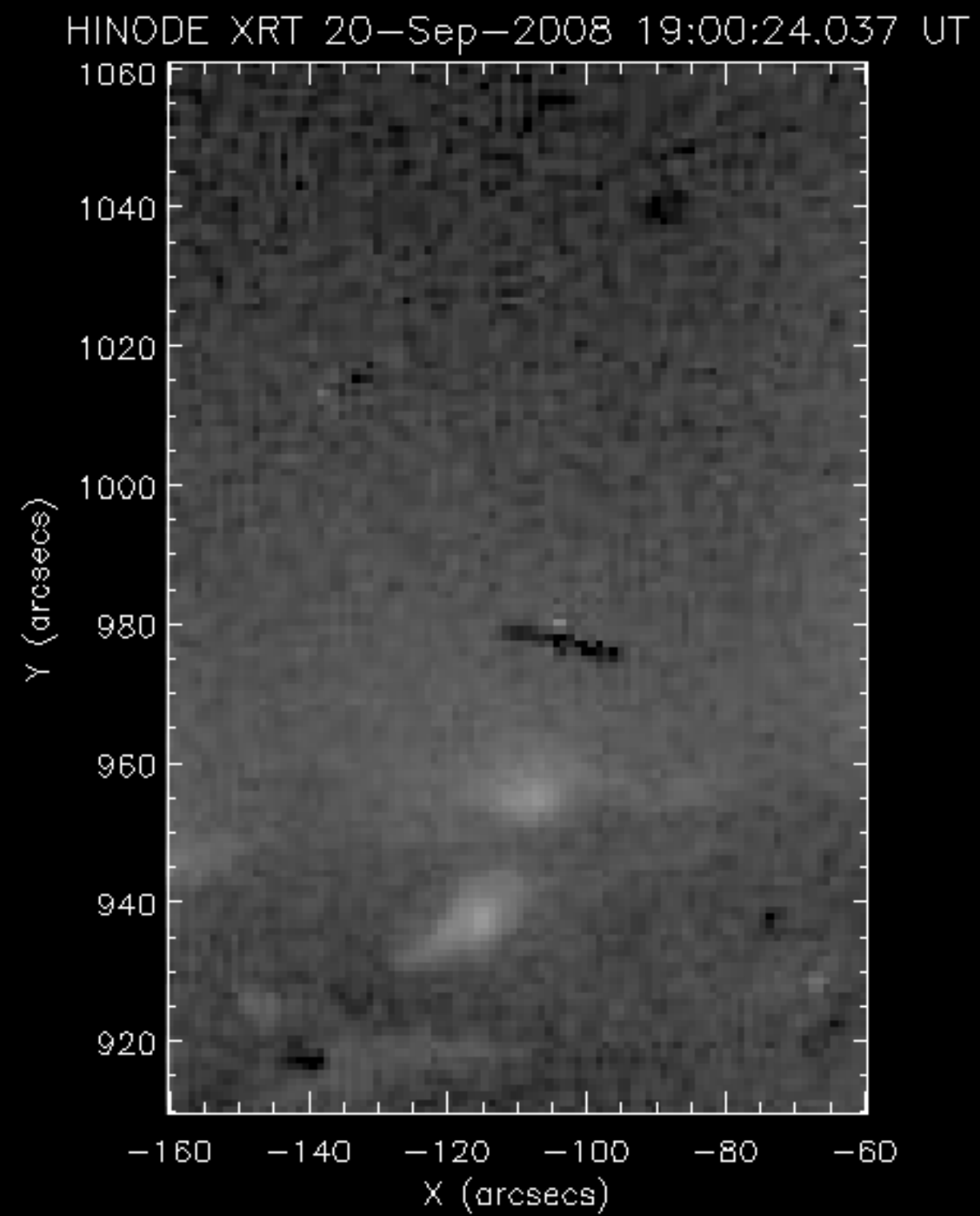
- 🔦 Complex, broad spire
- 🔦 Strong X-ray base brightening at base
- 🔦 Substantial cool ejective jet

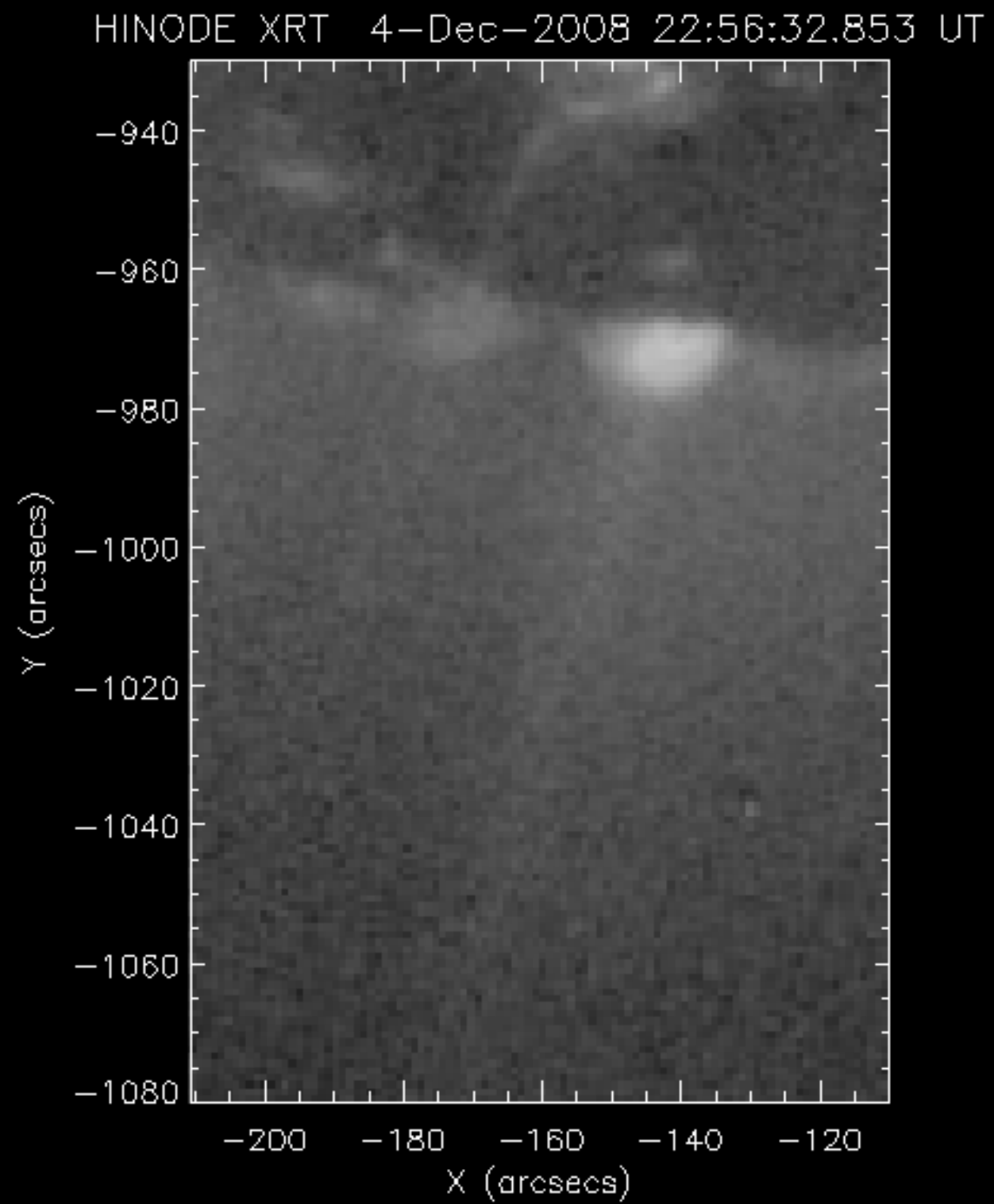
“Standard Jet” Examples

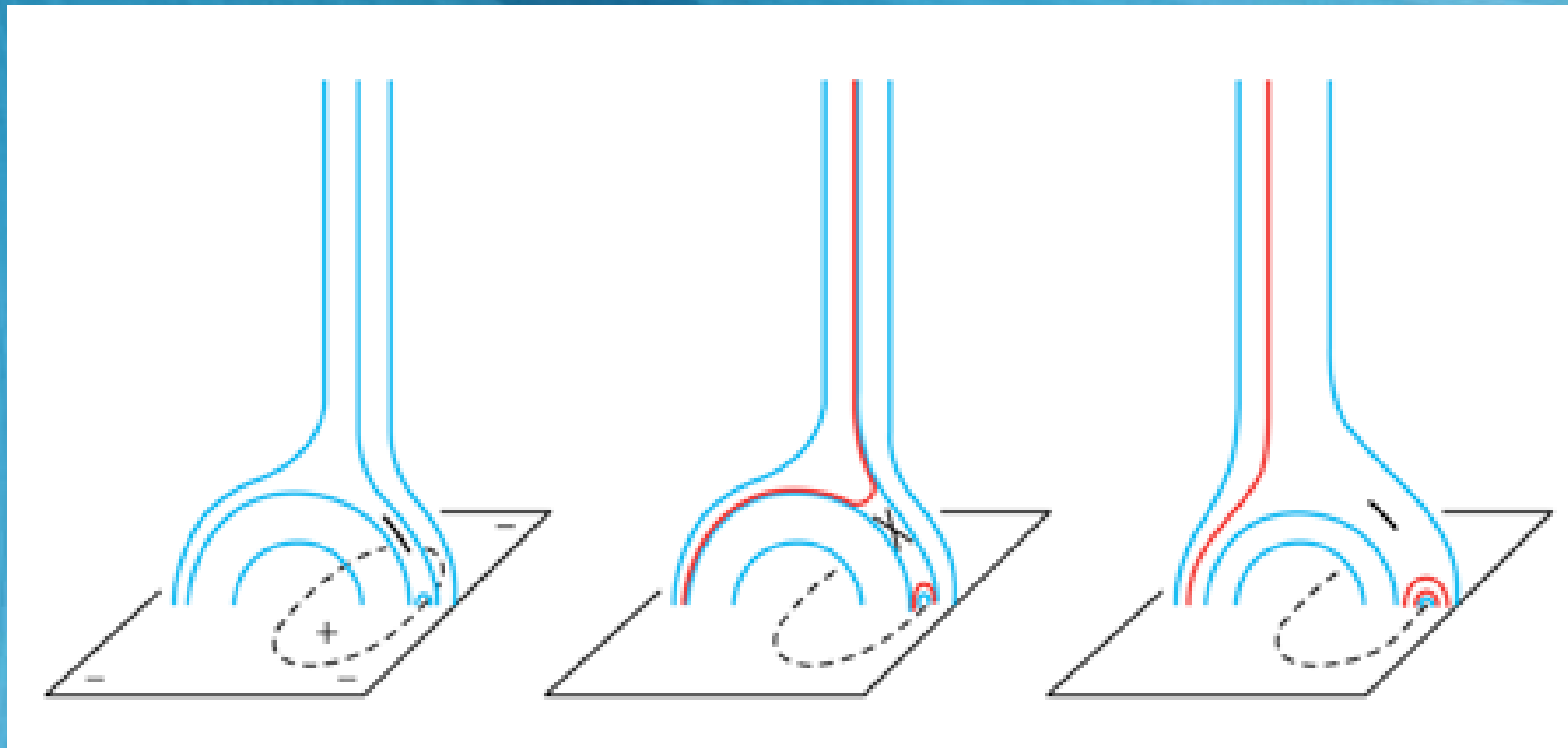




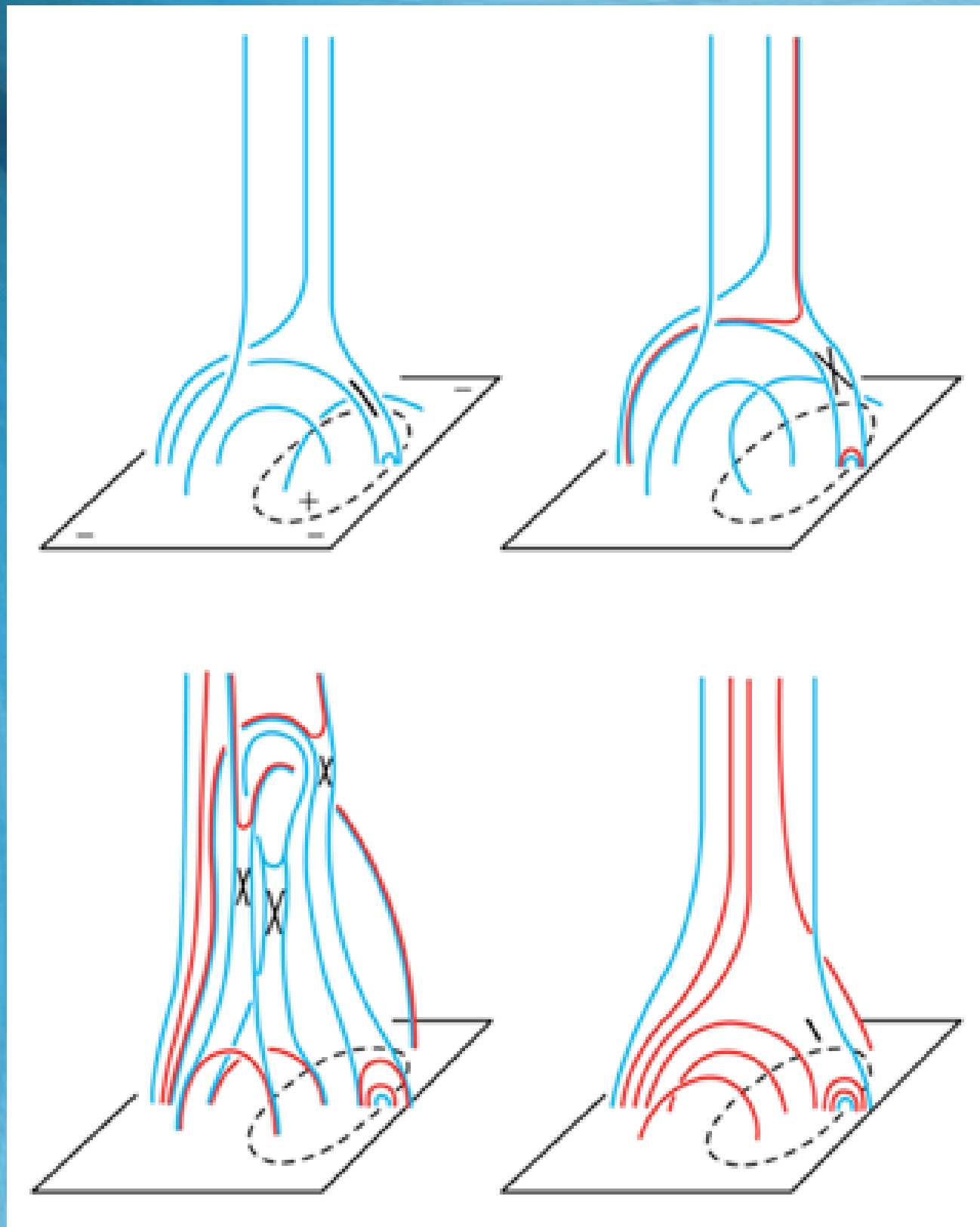
“Blowout Jet” Examples







Moore et al. (2010)



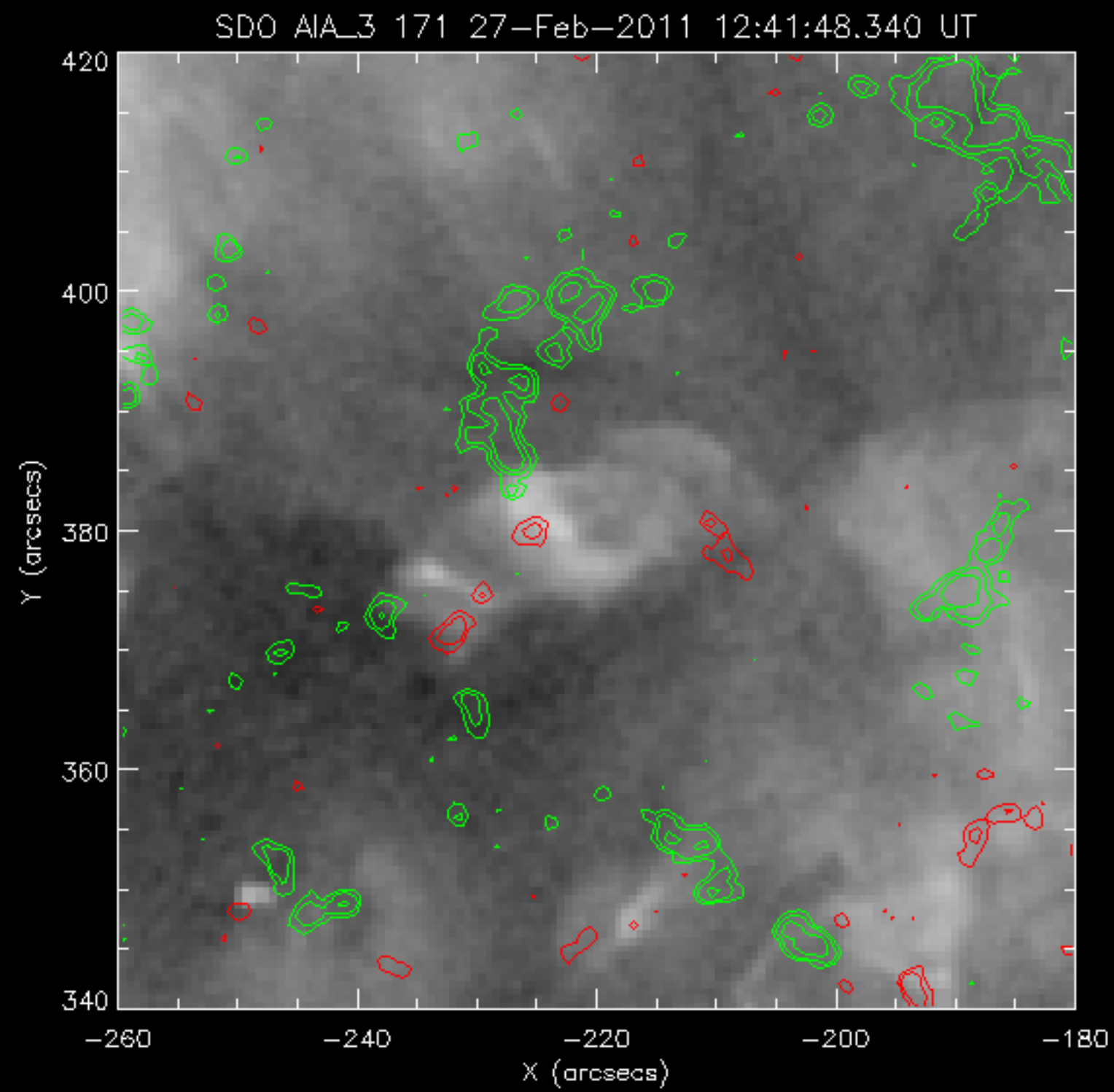
Moore et al. (2010)

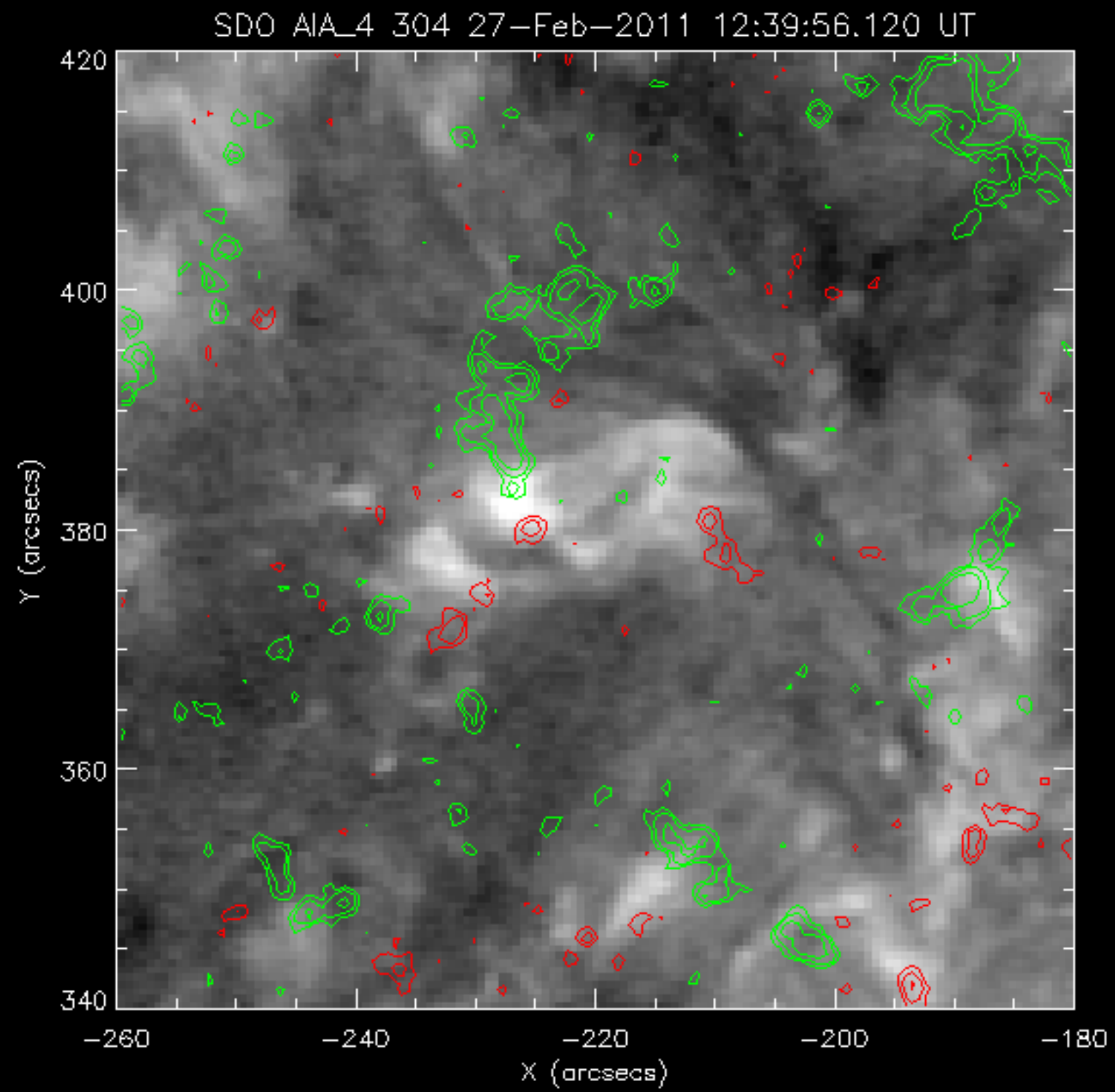
Jets with AIA (mainly our work)

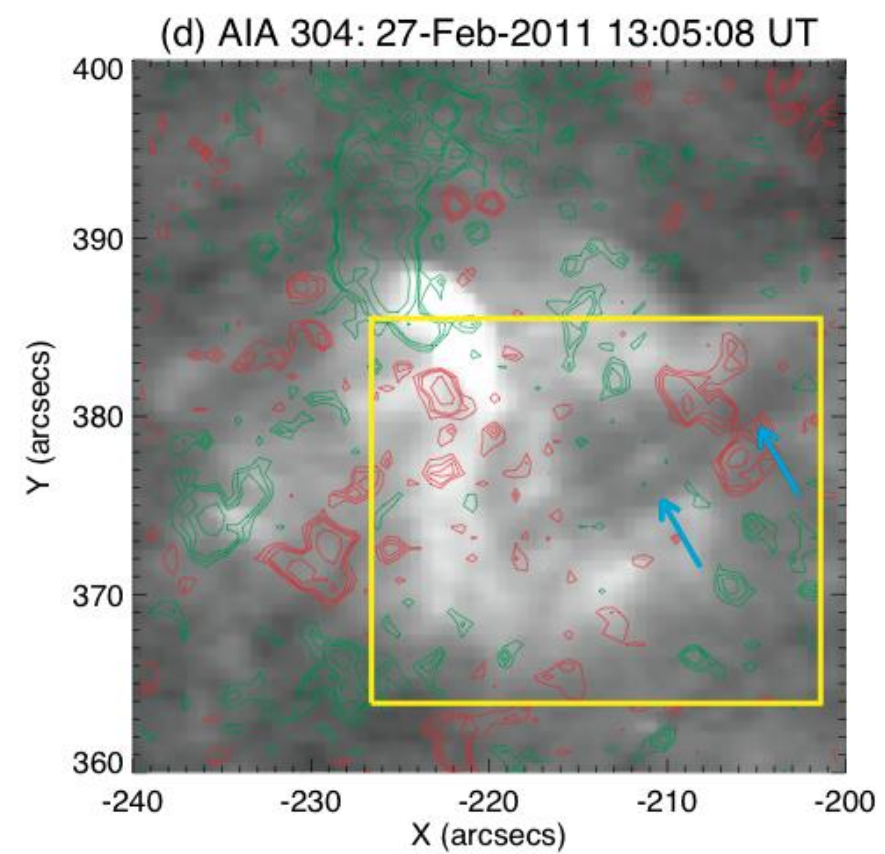
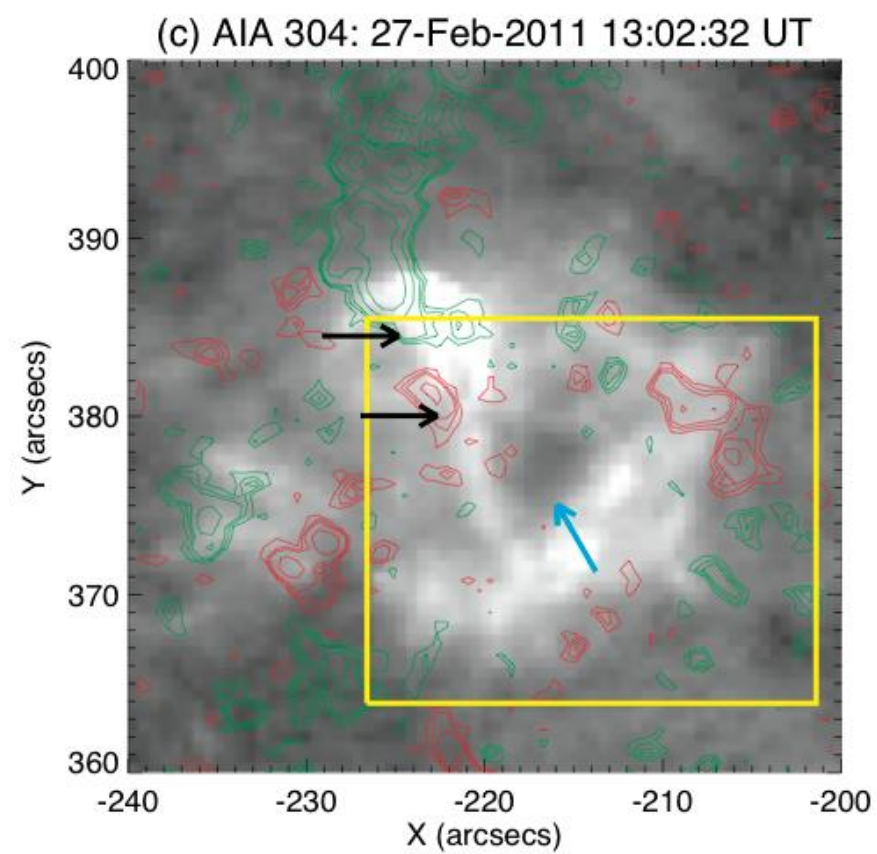
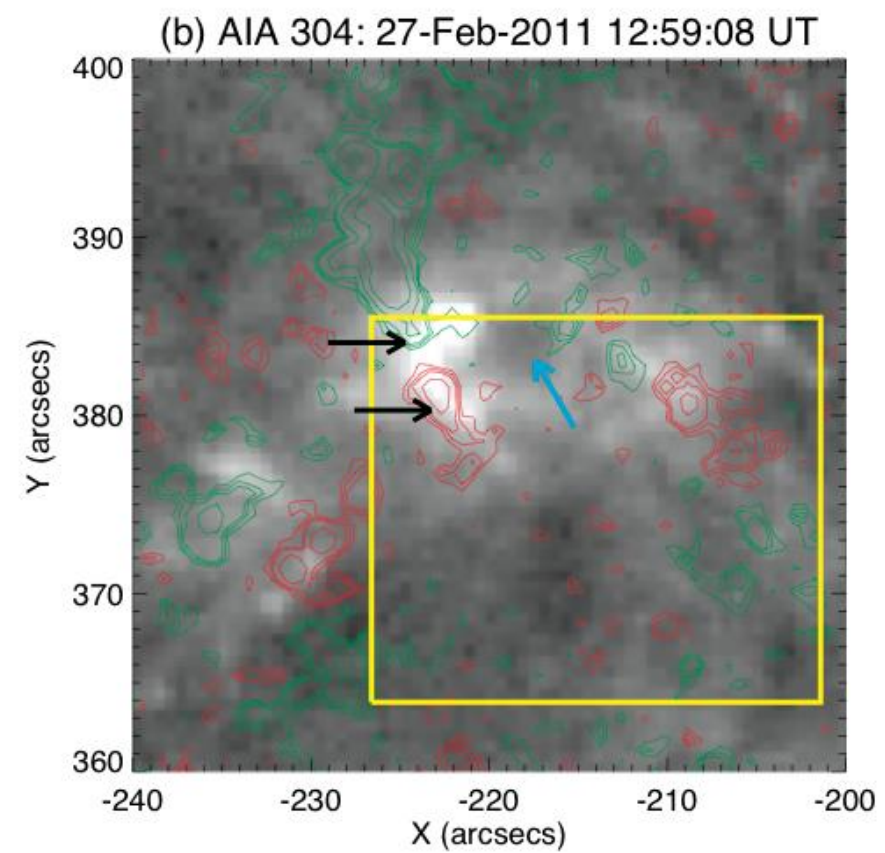
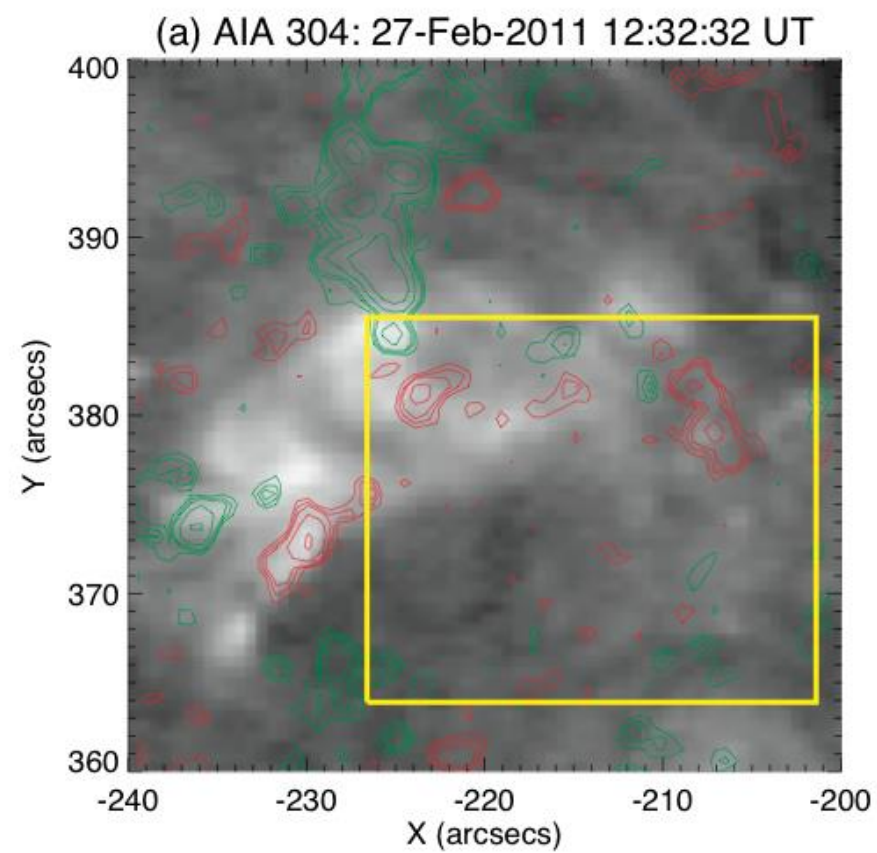
On-Disk Macrospicule

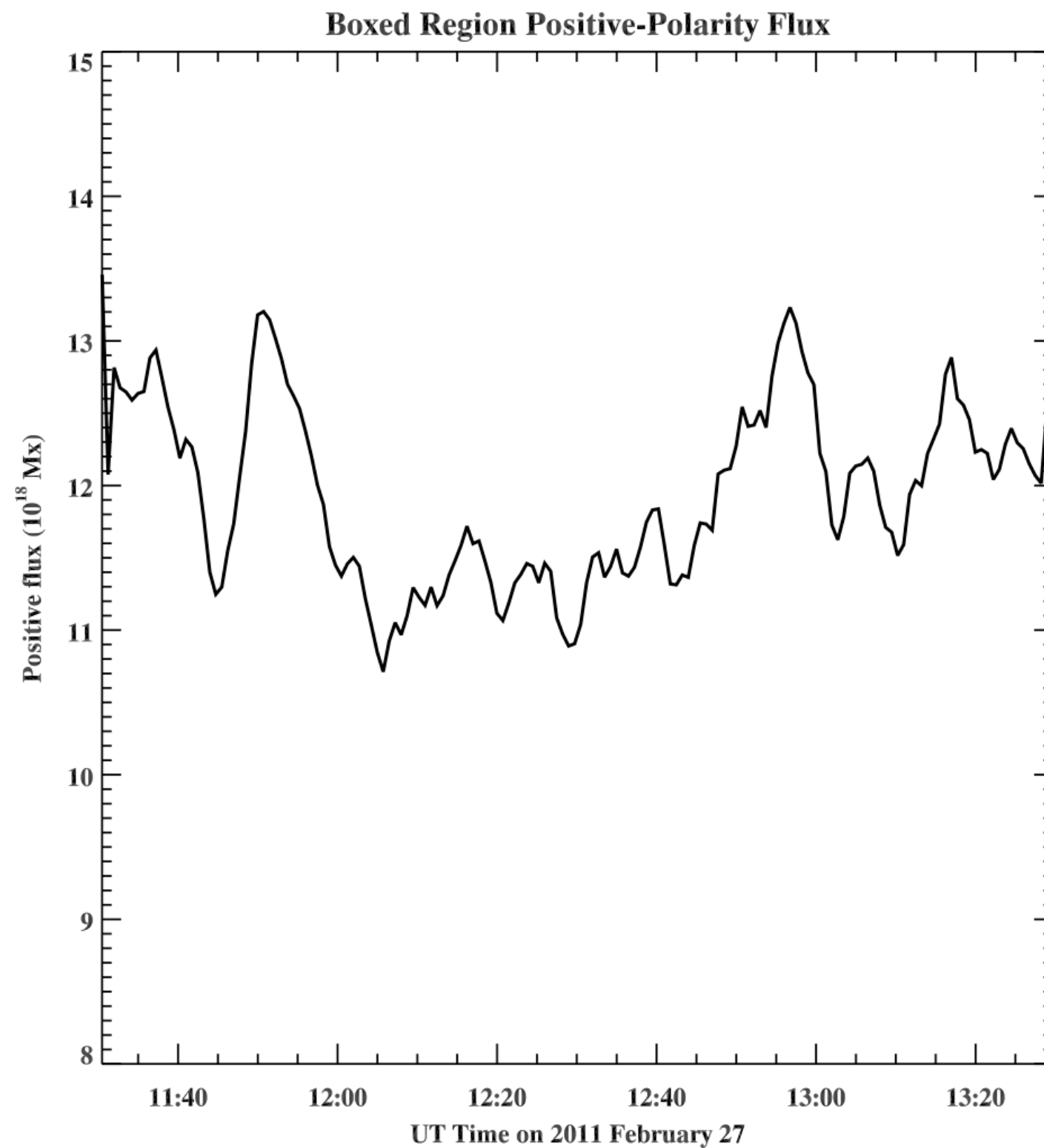
(Mitzi Adams, Sterling, Moore, & Gary 2014)

- 🔦 AIA and HMI observations.
- 🔦 In on-disk Coronal Hole.
- 🔦 No obvious AIA hot-channel jet; therefore might be a “macrospicule,” but not certain (X-rays??)..
- 🔦 On-disk, so look for Shibata/Moore EFR source for the jet.



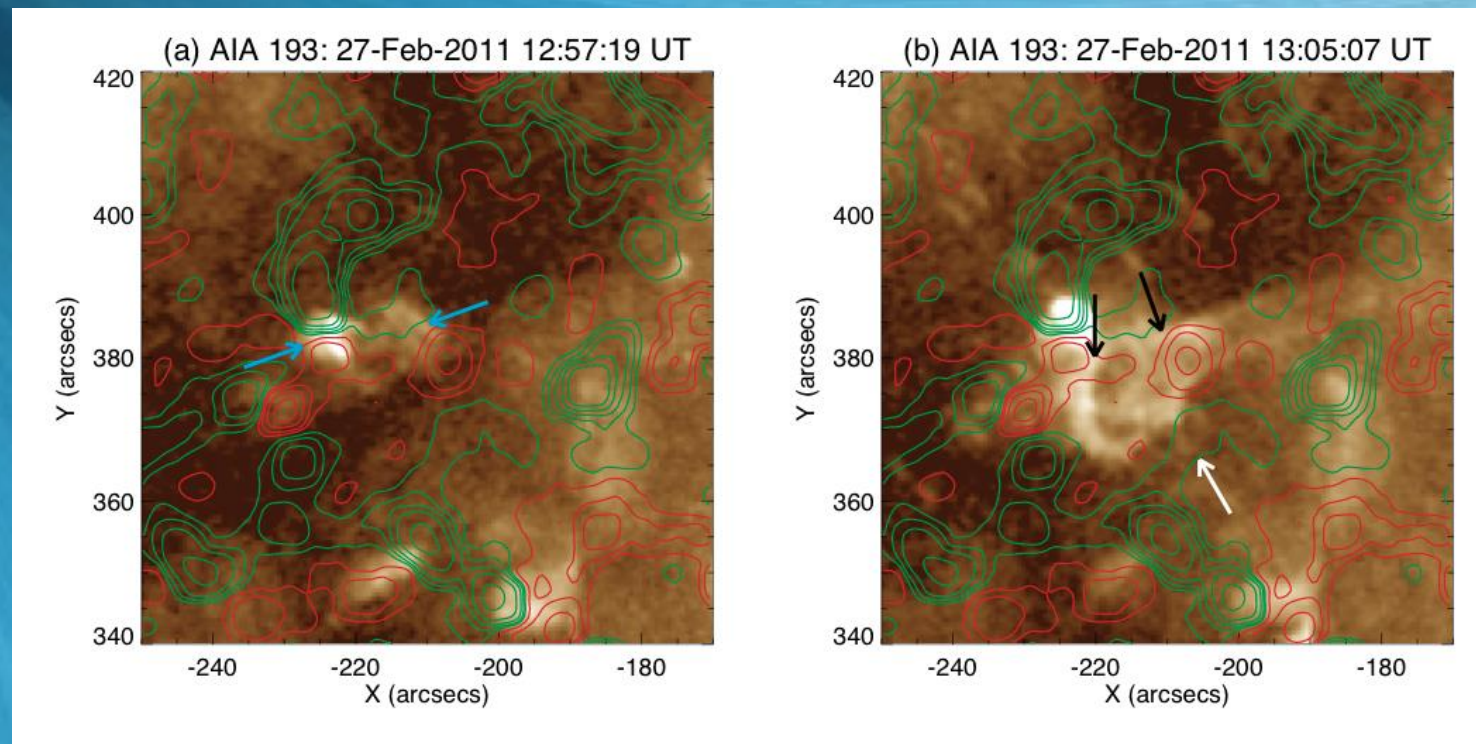




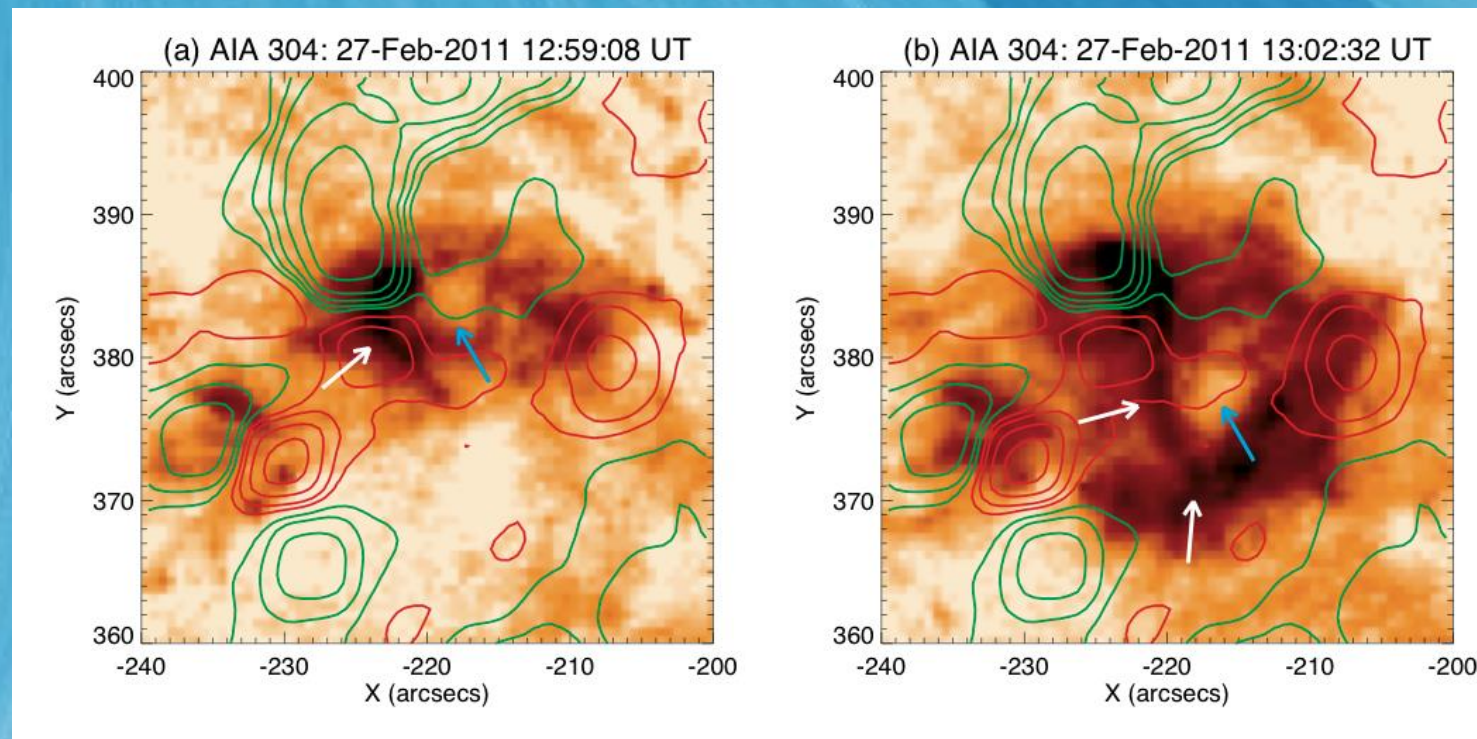


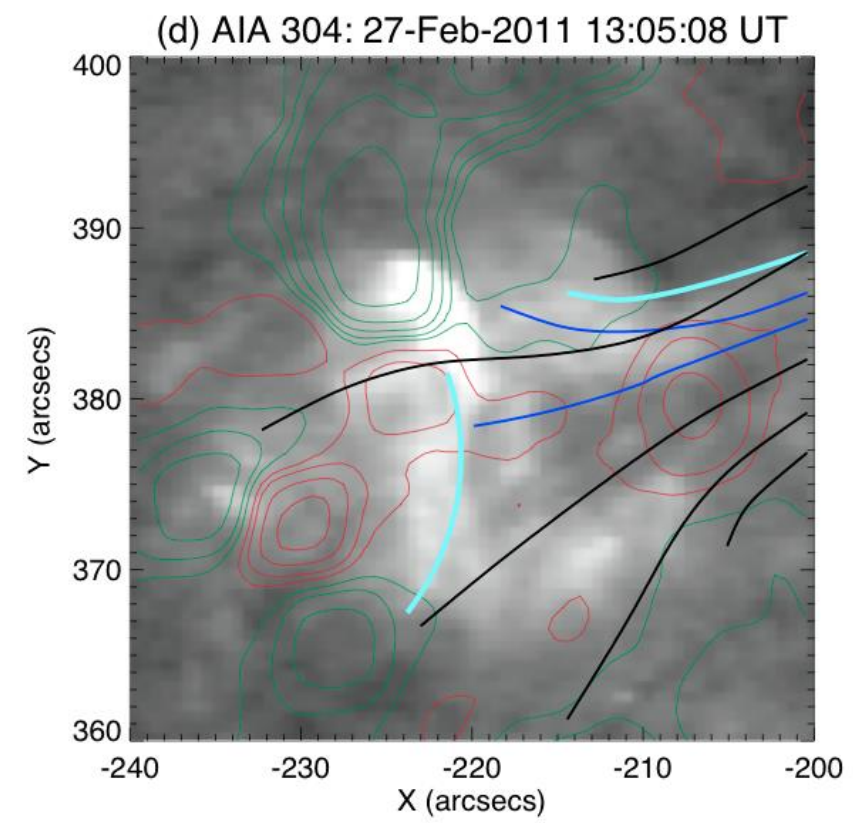
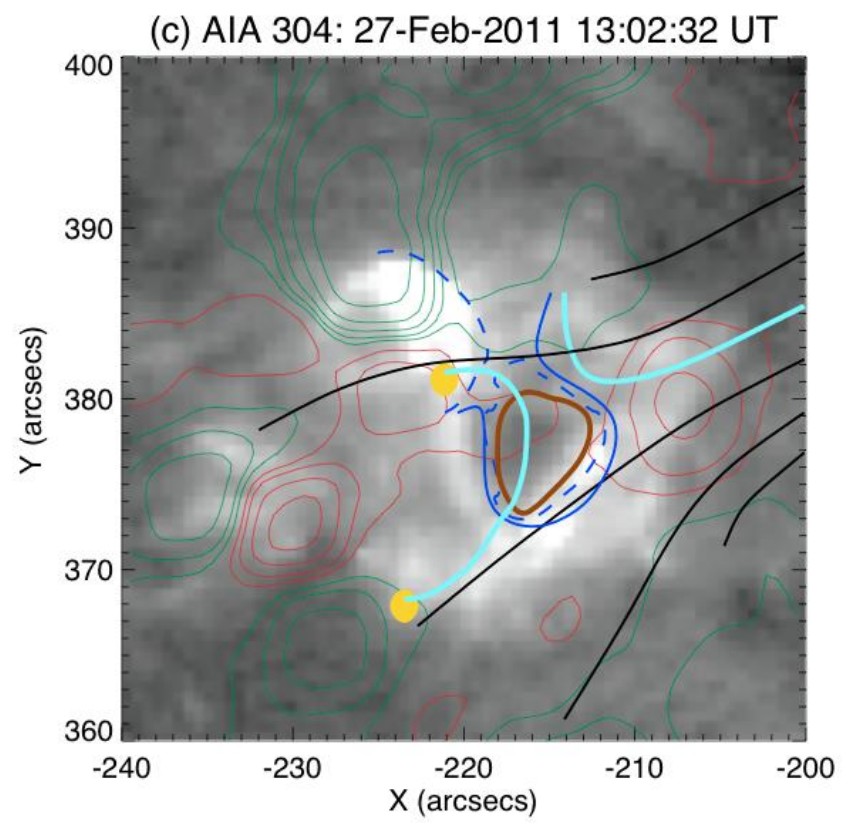
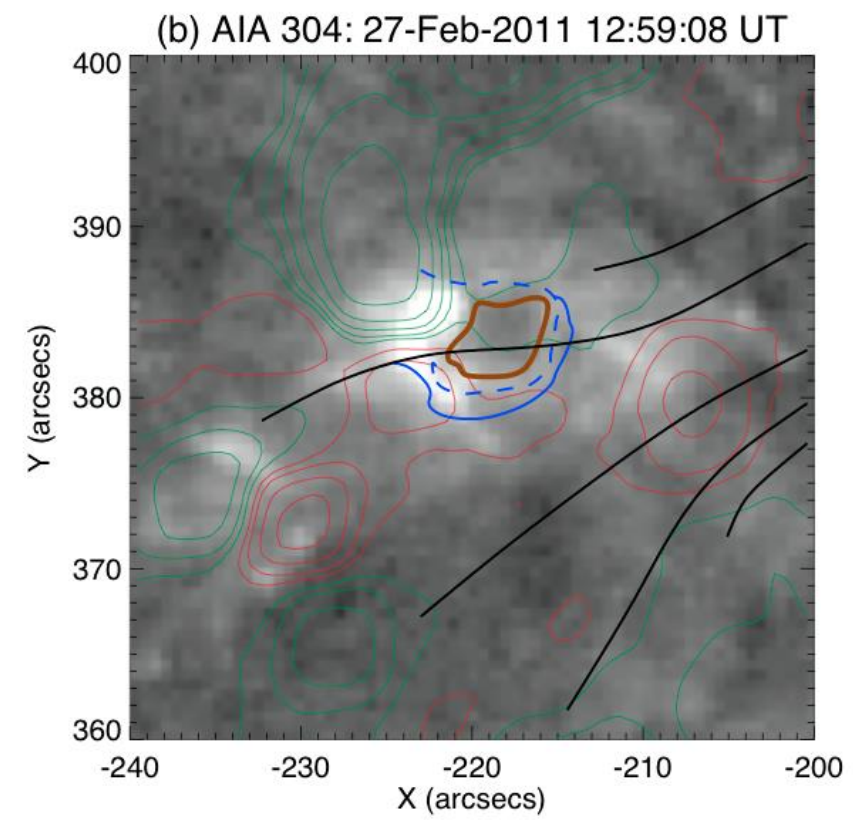
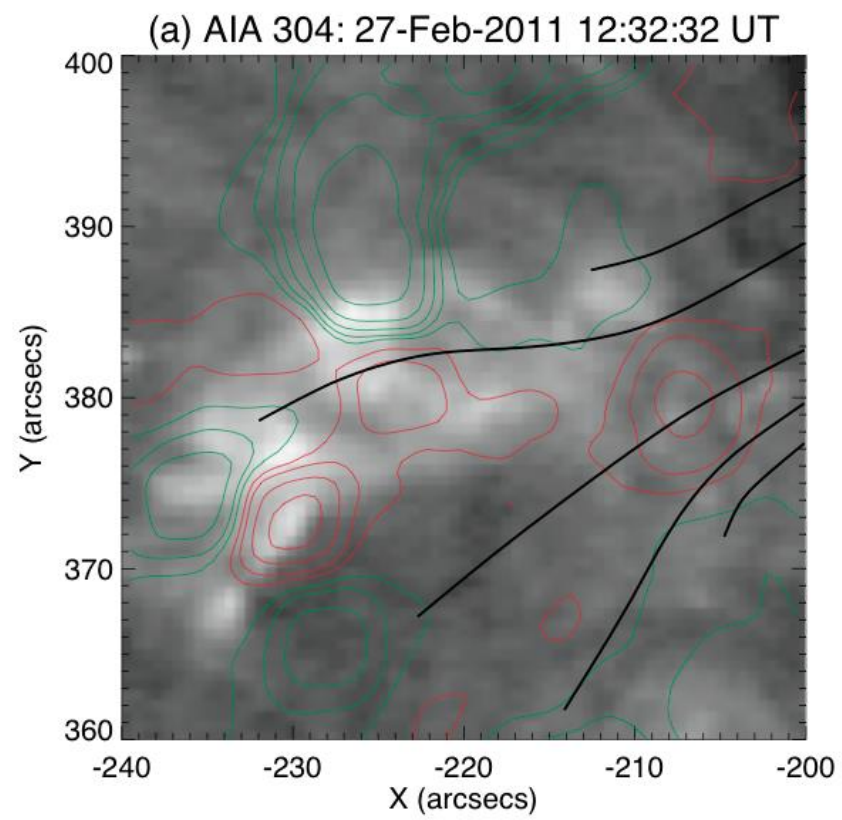
Variation $< \sim 20\%$; trend $< \sim 2 \times 10^{15}$ Mx/s
 \Rightarrow EF probably not driving the jet
(cf. Chandrashekhar et al. 2014)

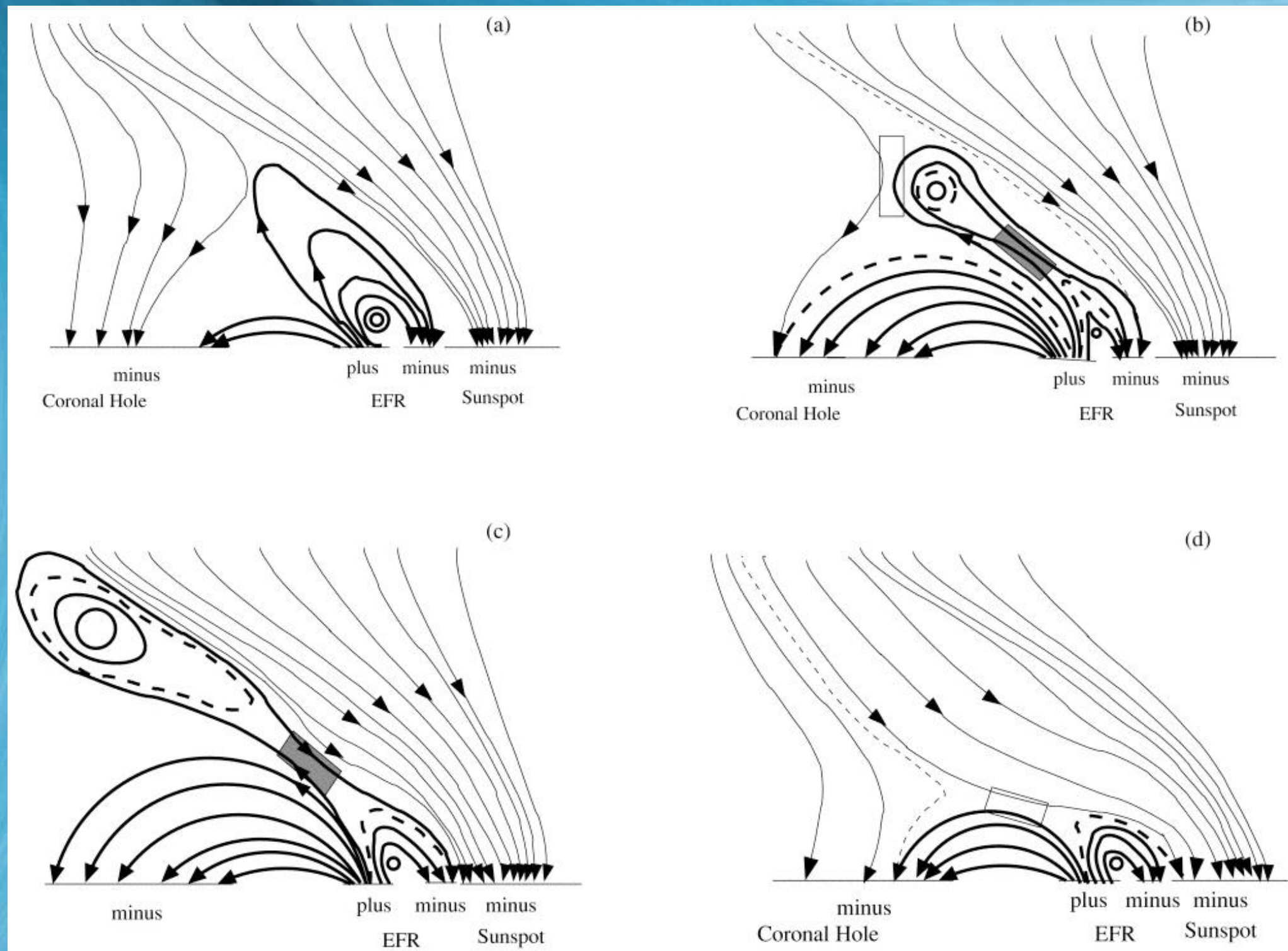
Also, no strong bipole under jet:

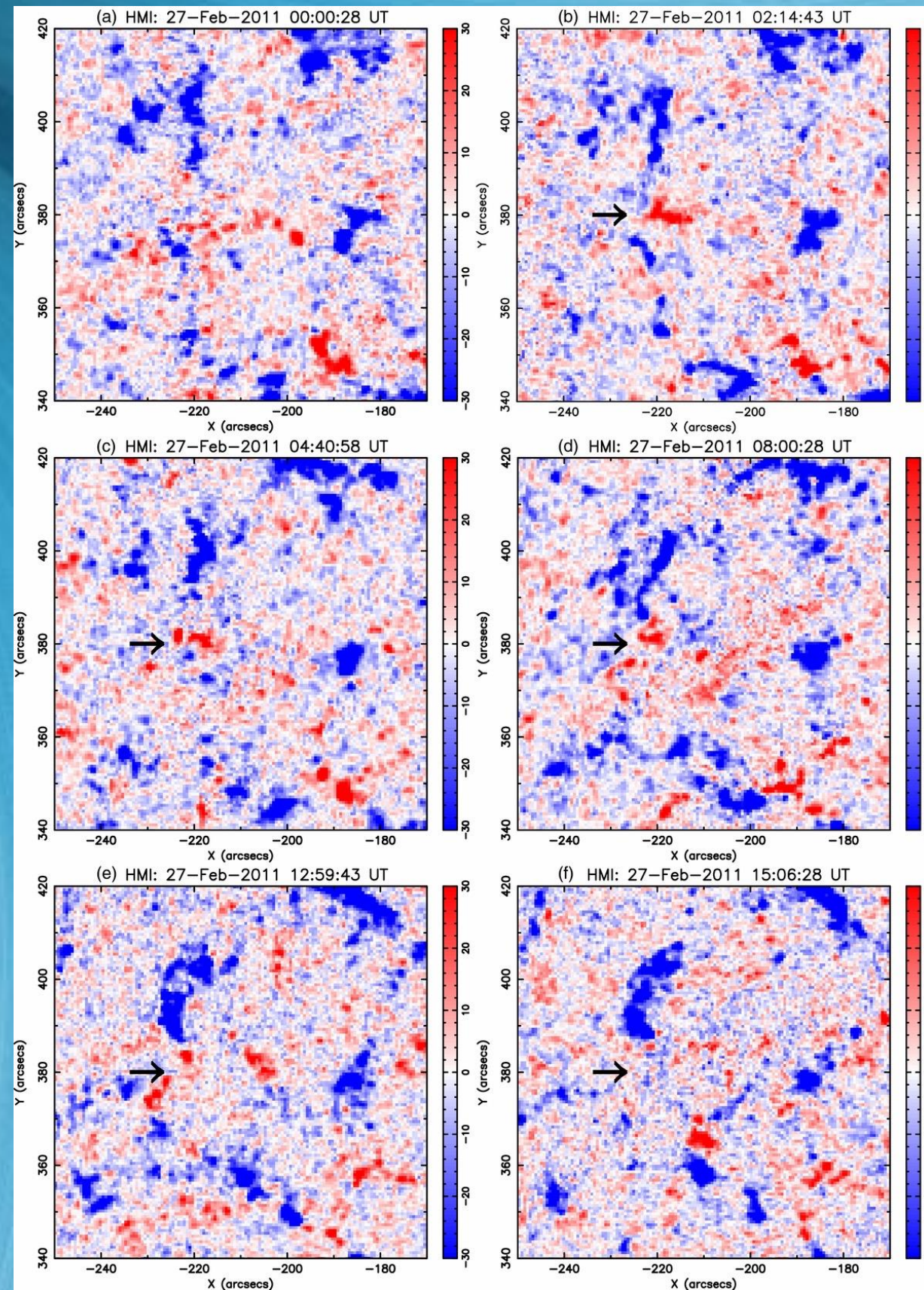


Instead, probably have filament material from neutral line:









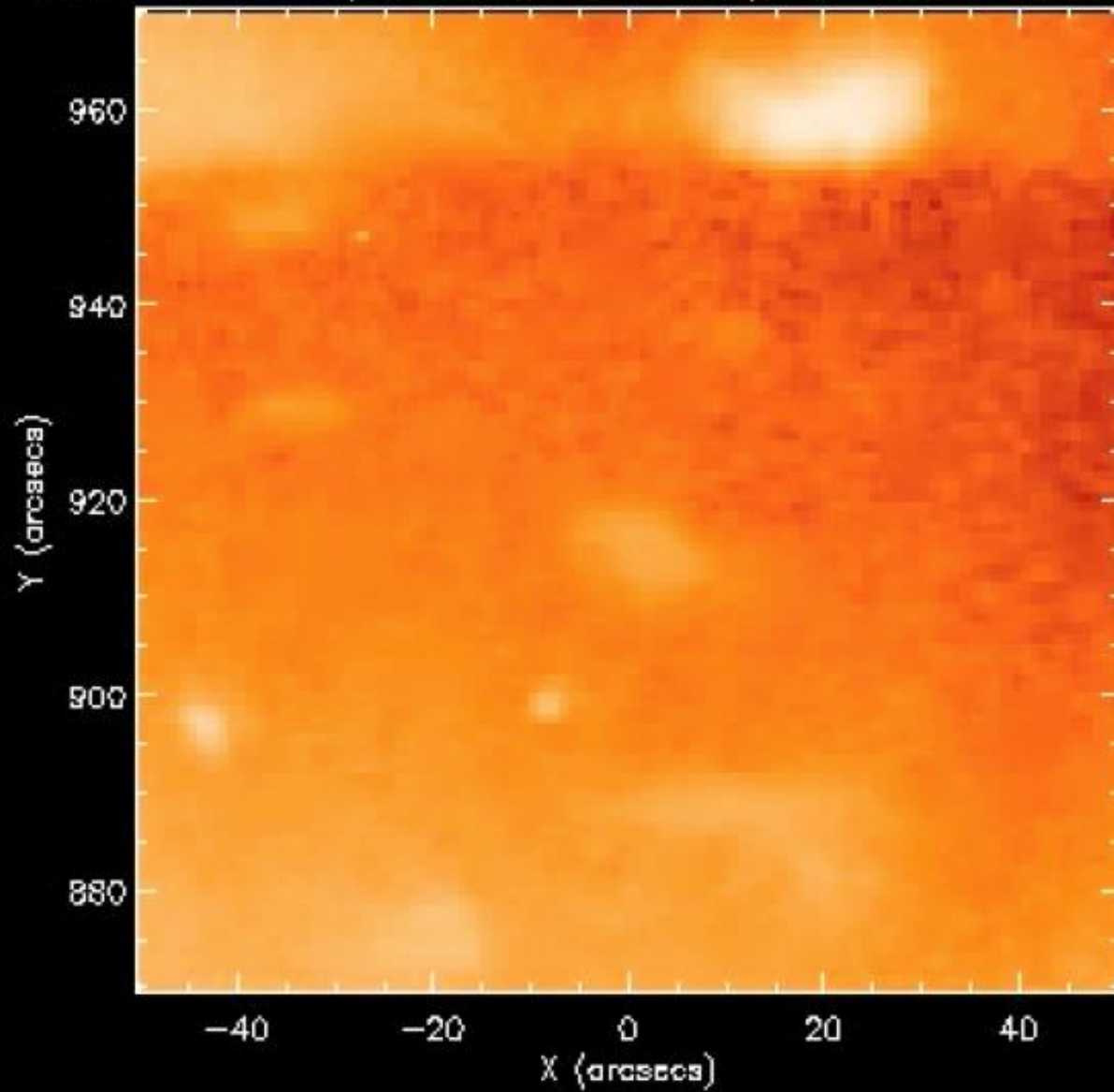
In this case, instead of emerging flux, have *canceling* flux!

With this background in mind, look at more events with AIA data

- ♦ Studied 20 Hinode/XRT X-ray jets polar coronal holes during SDO period.
- ♦ These jets were randomly selected during a previous investigation (Moore et al. 2013).
- ♦ For first several jets, examined all seven SDO/AIA EUV channels.
- ♦ For remaining jets, only examined AIA 304, 171, 193, and 211Å channels (~ 0.05 , 0.6, 1.6, and 2.0 MK, respectively).

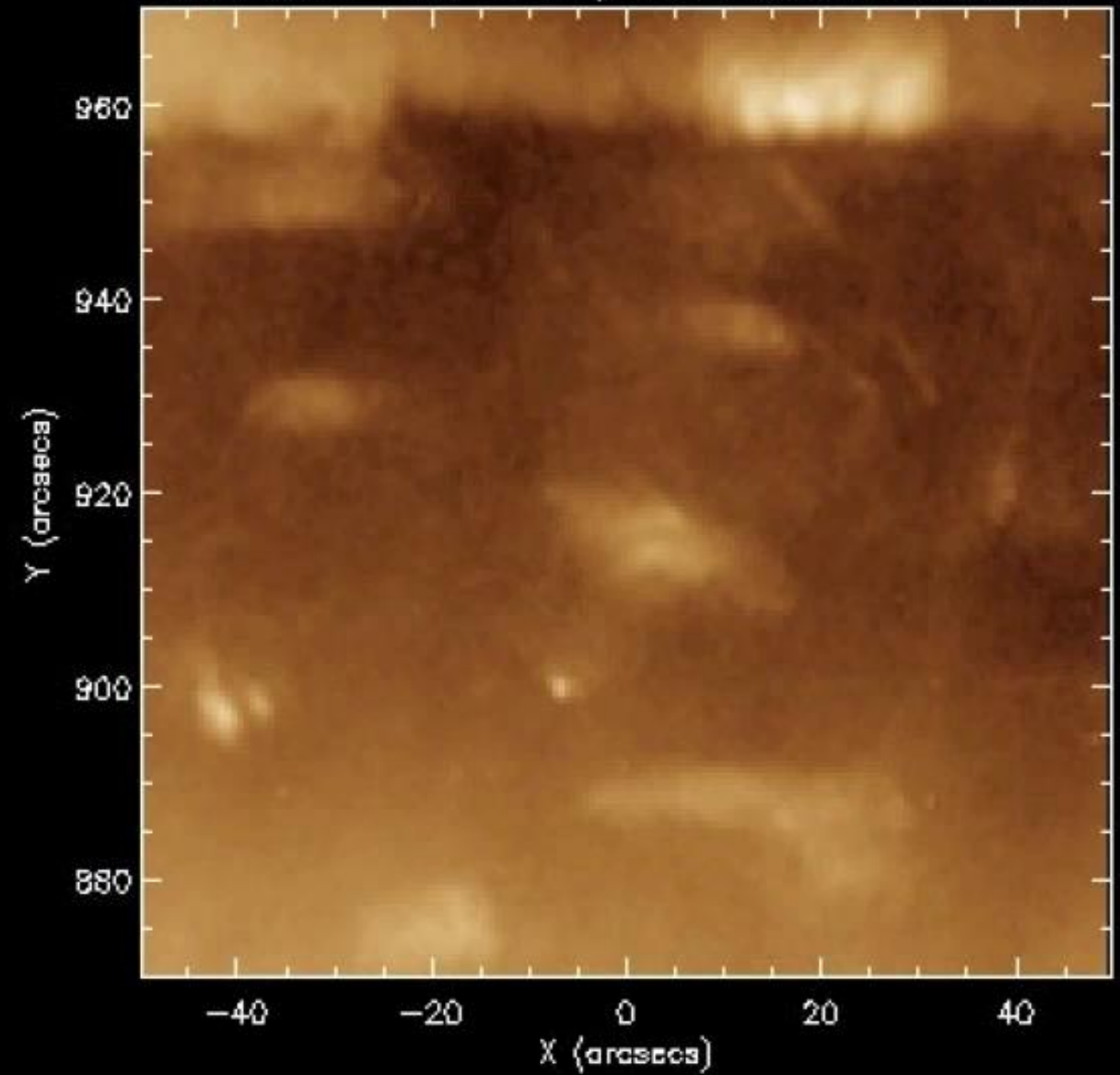
XRT

HINODE XRT JAXA/ISAS, SIRIUS 9-Sep-2010 21:50:23.471



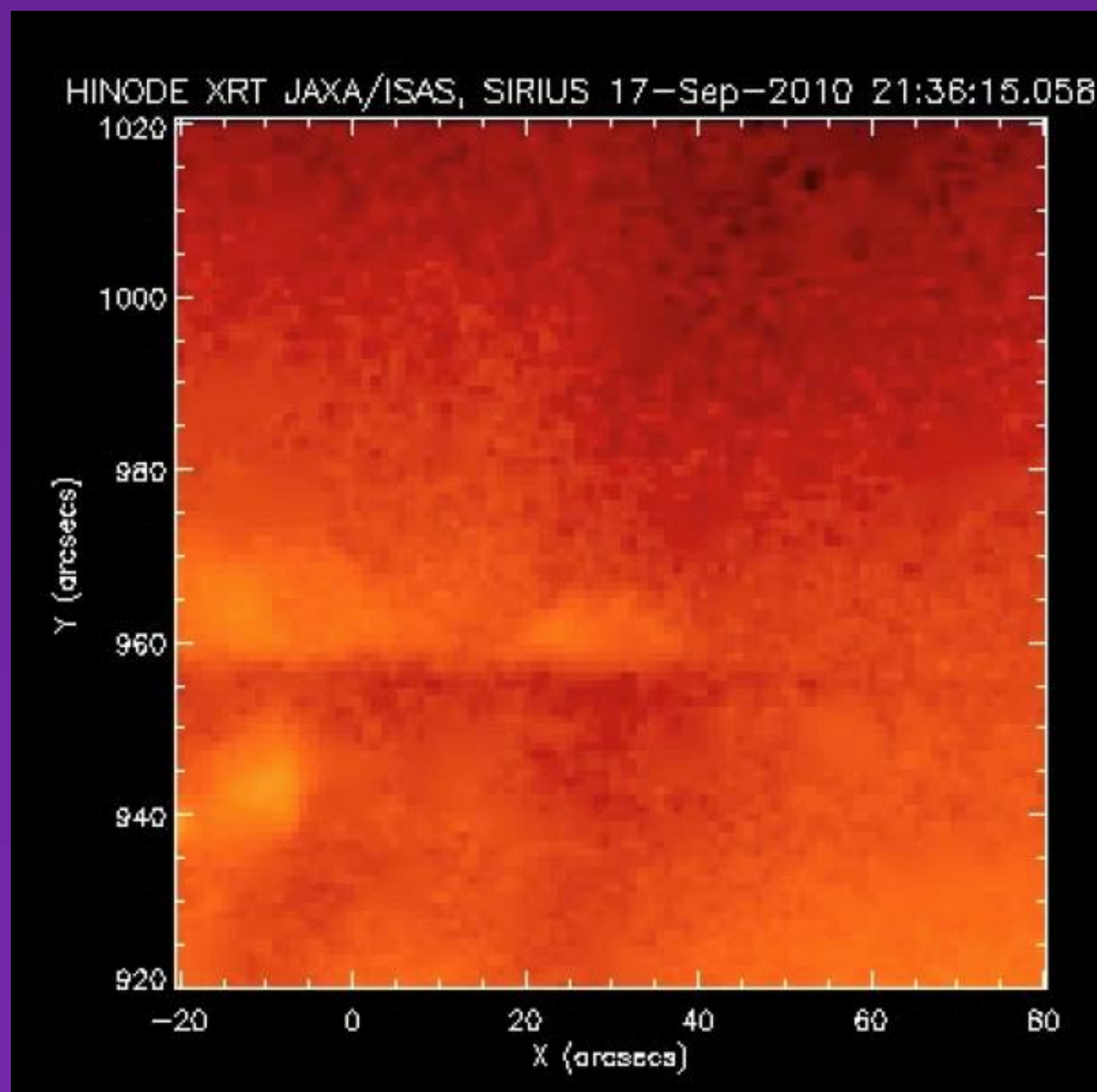
AIA 193

SDO AIA_2 193 9-Sep-2010 21:50:06.630 UT

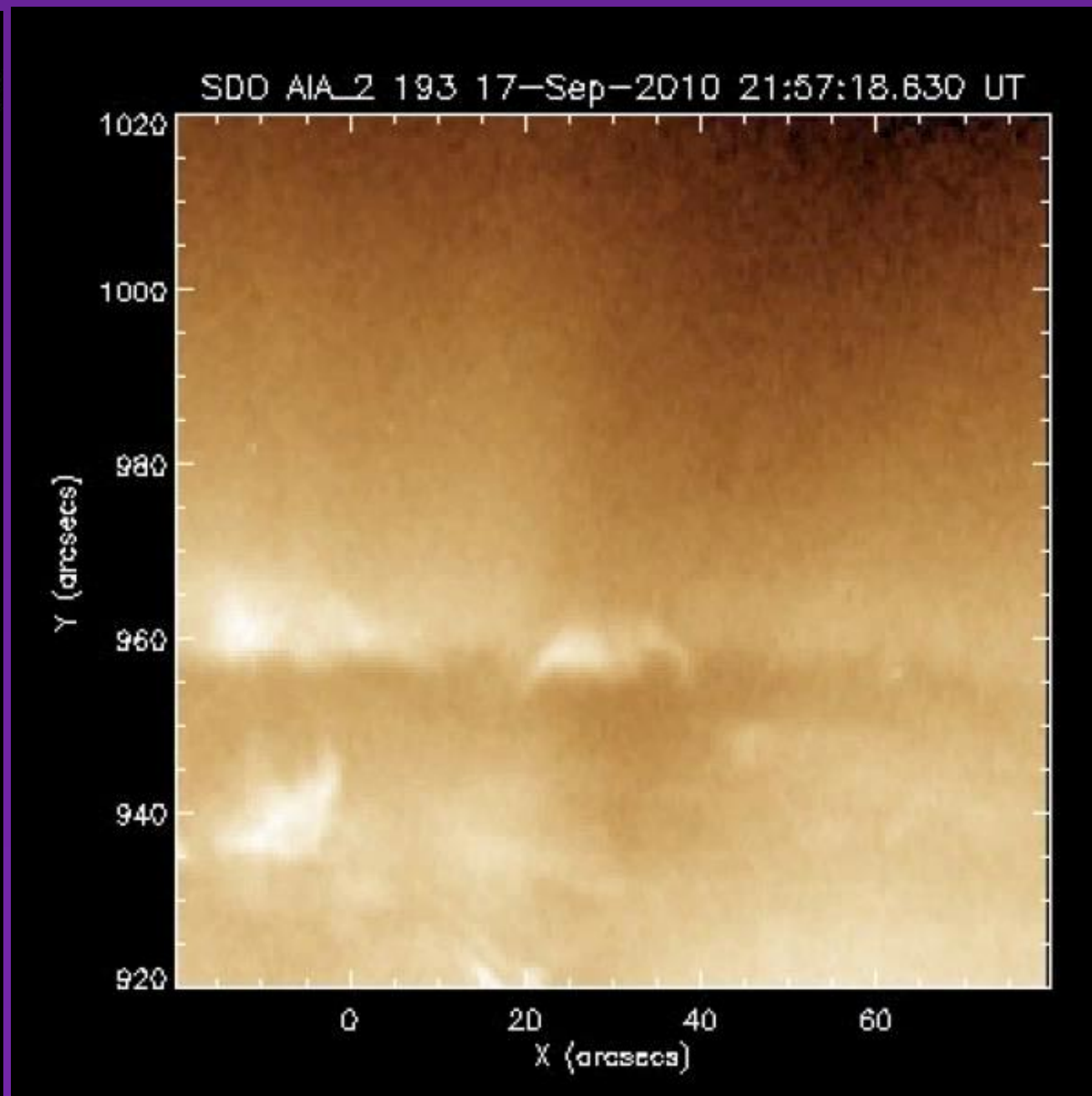


Event 12

XRT

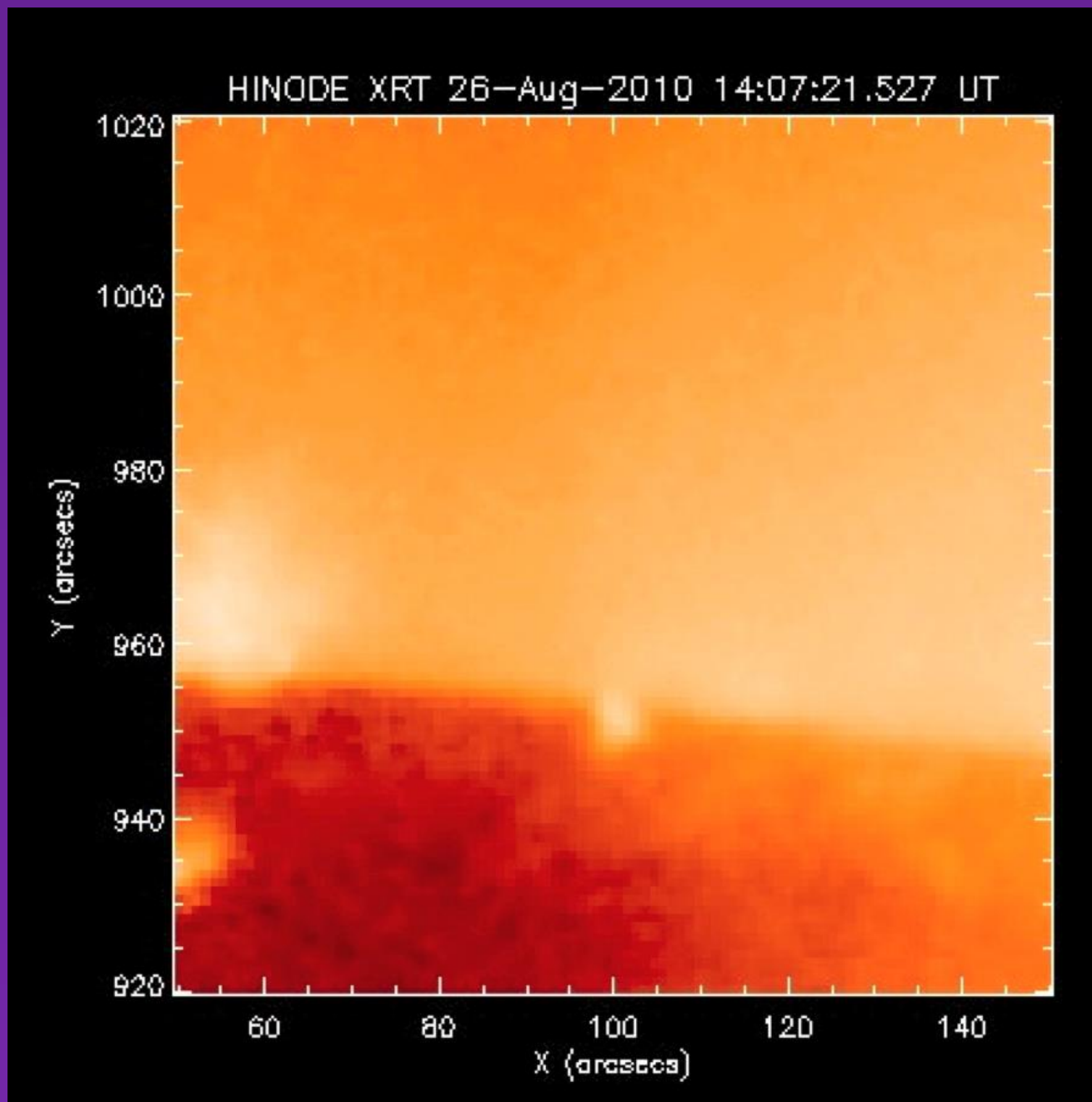


AIA 193

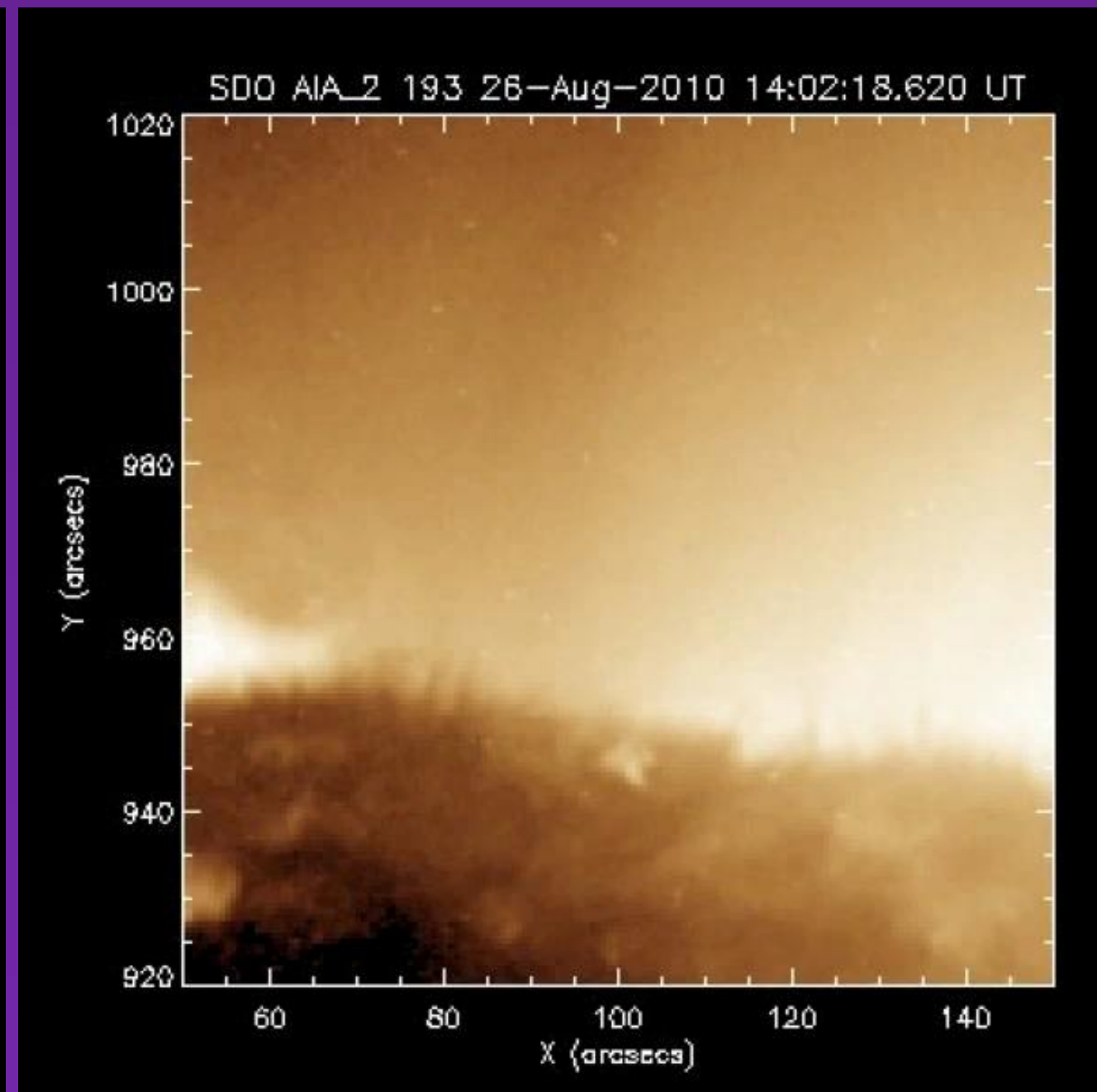


Event 18

XRT



AIA 193

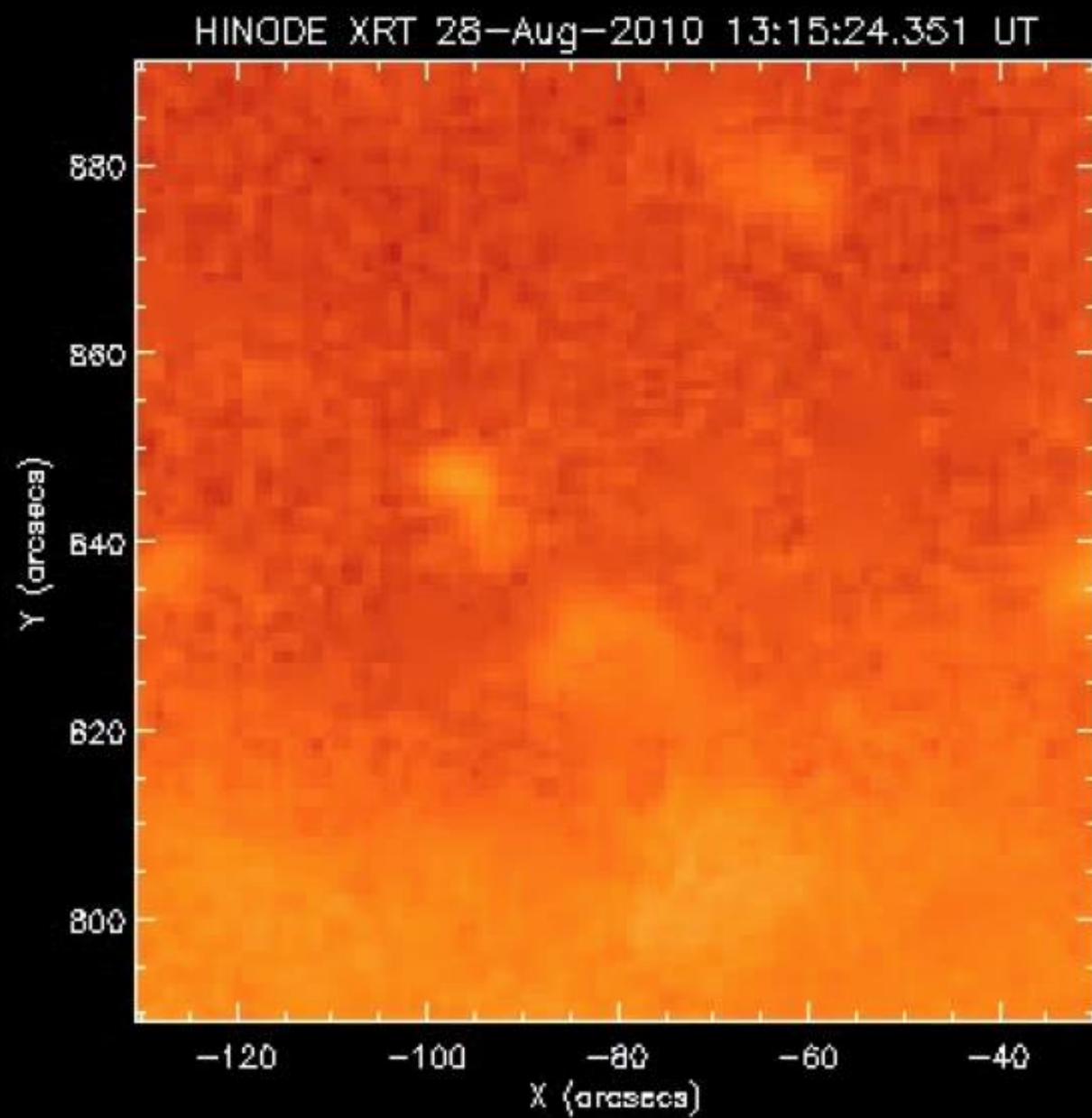


Event 3

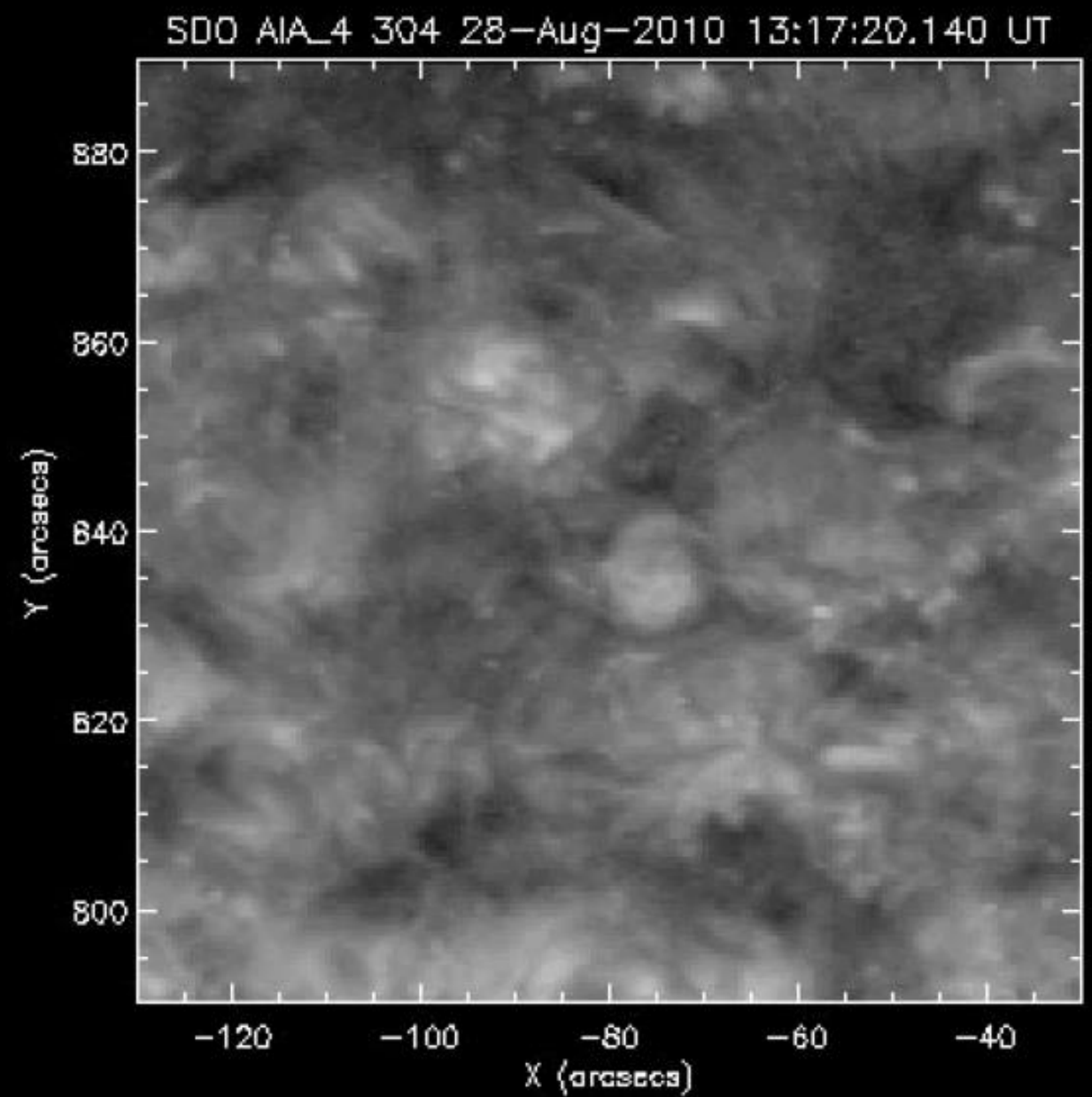
“Normal” Filament Eruption (TRACE)



XRT

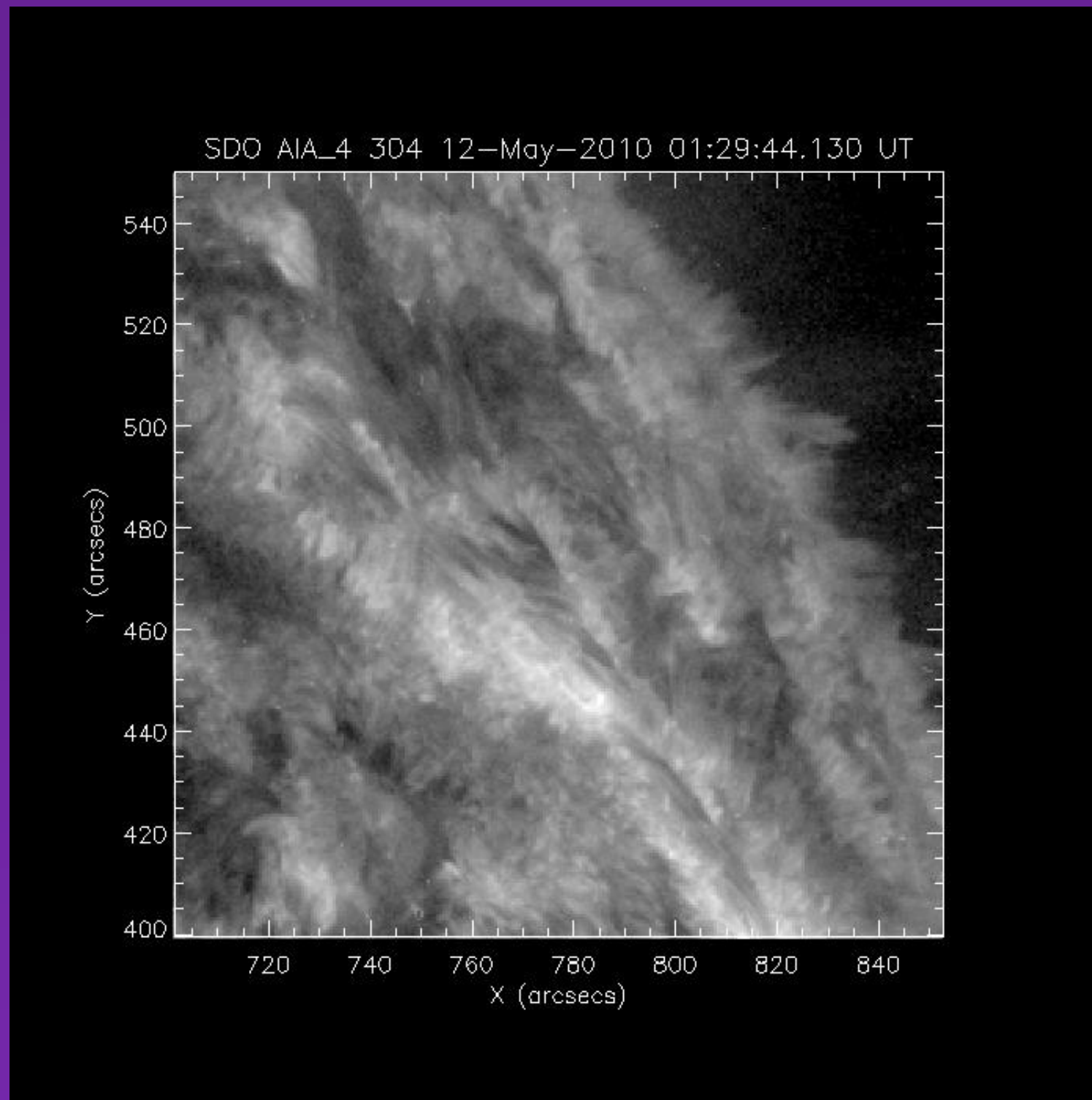


AIA 304

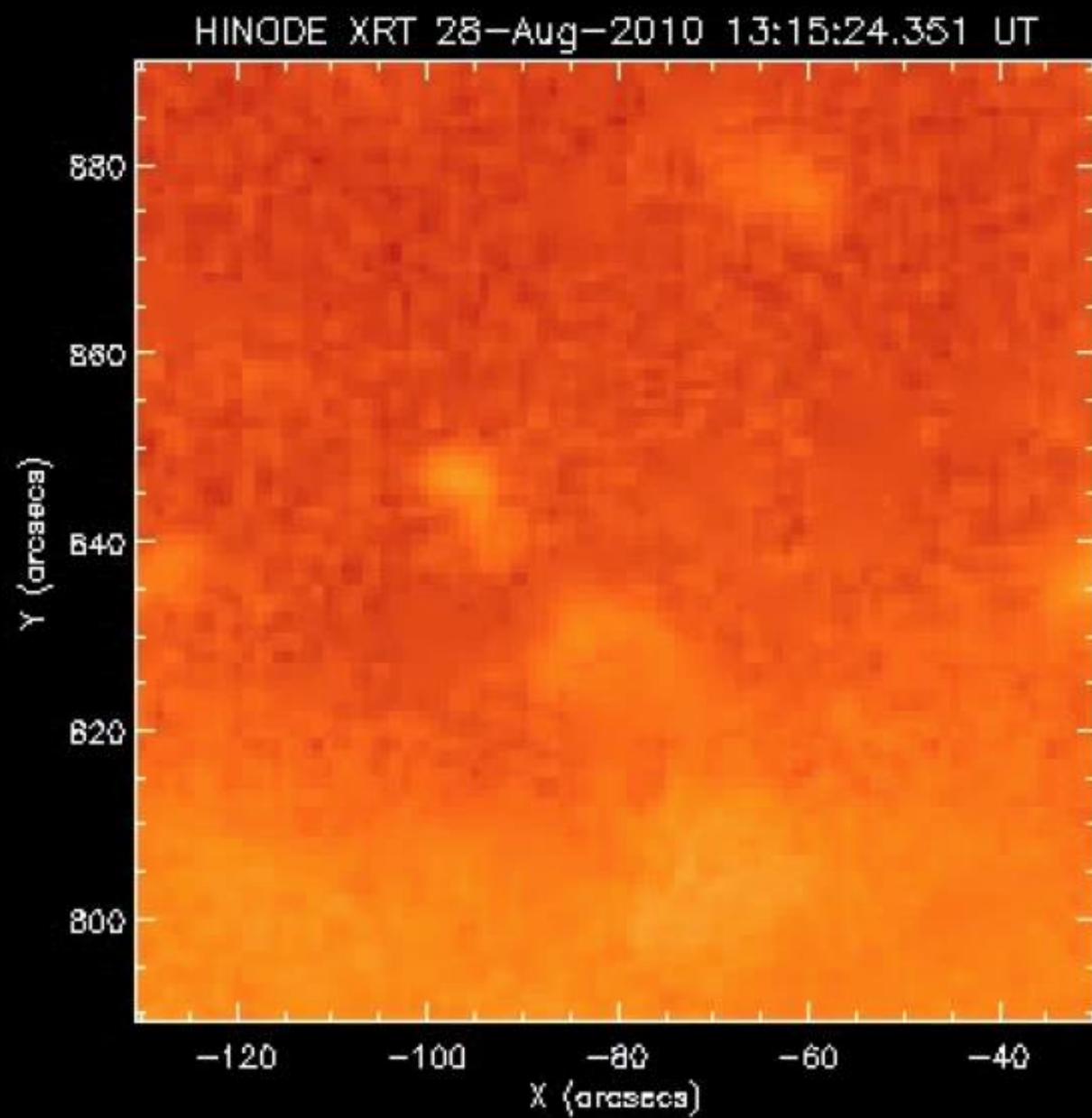


Event 7

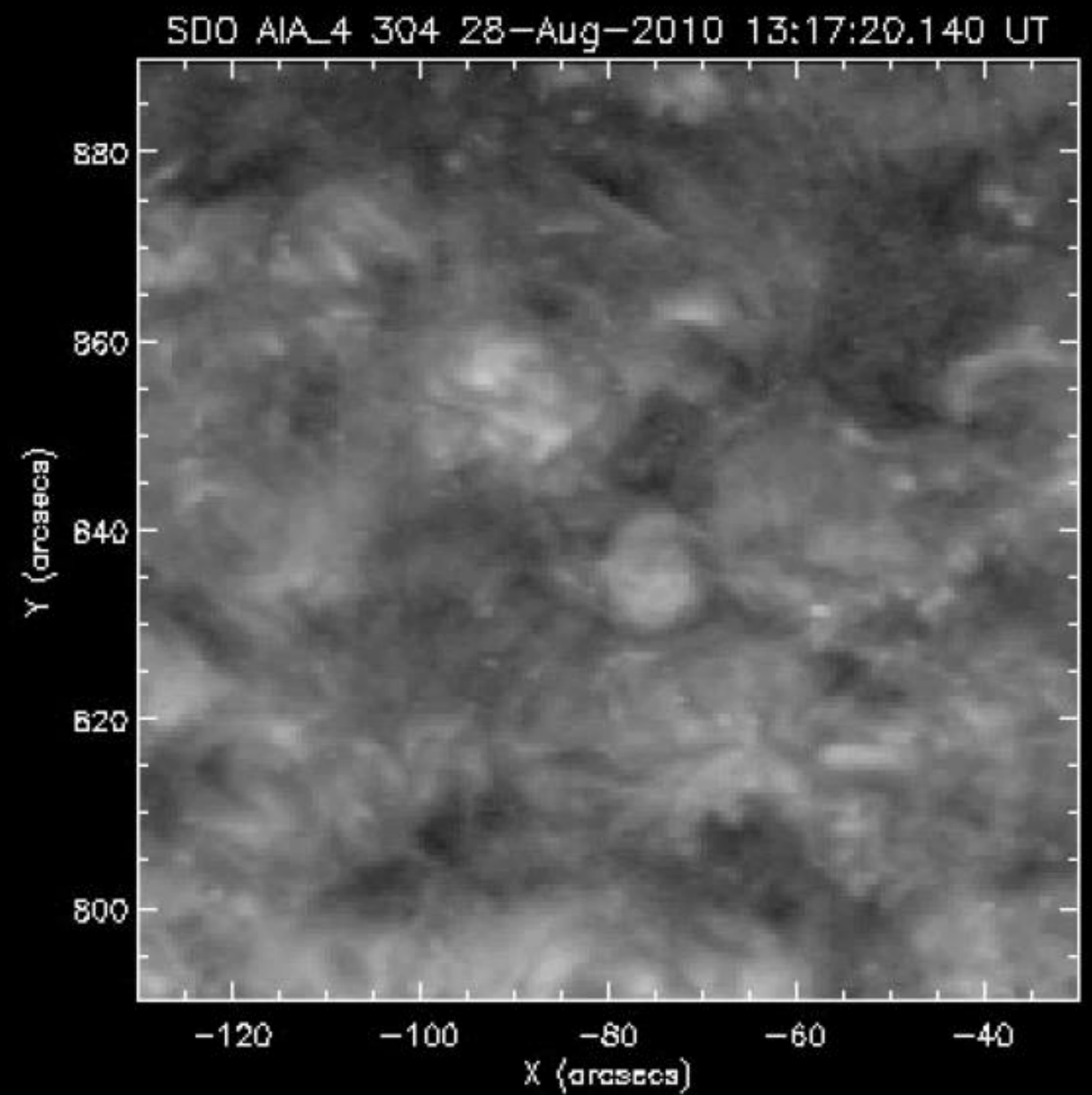
“Normal” Filament Confined Eruption (AIA 304)



XRT



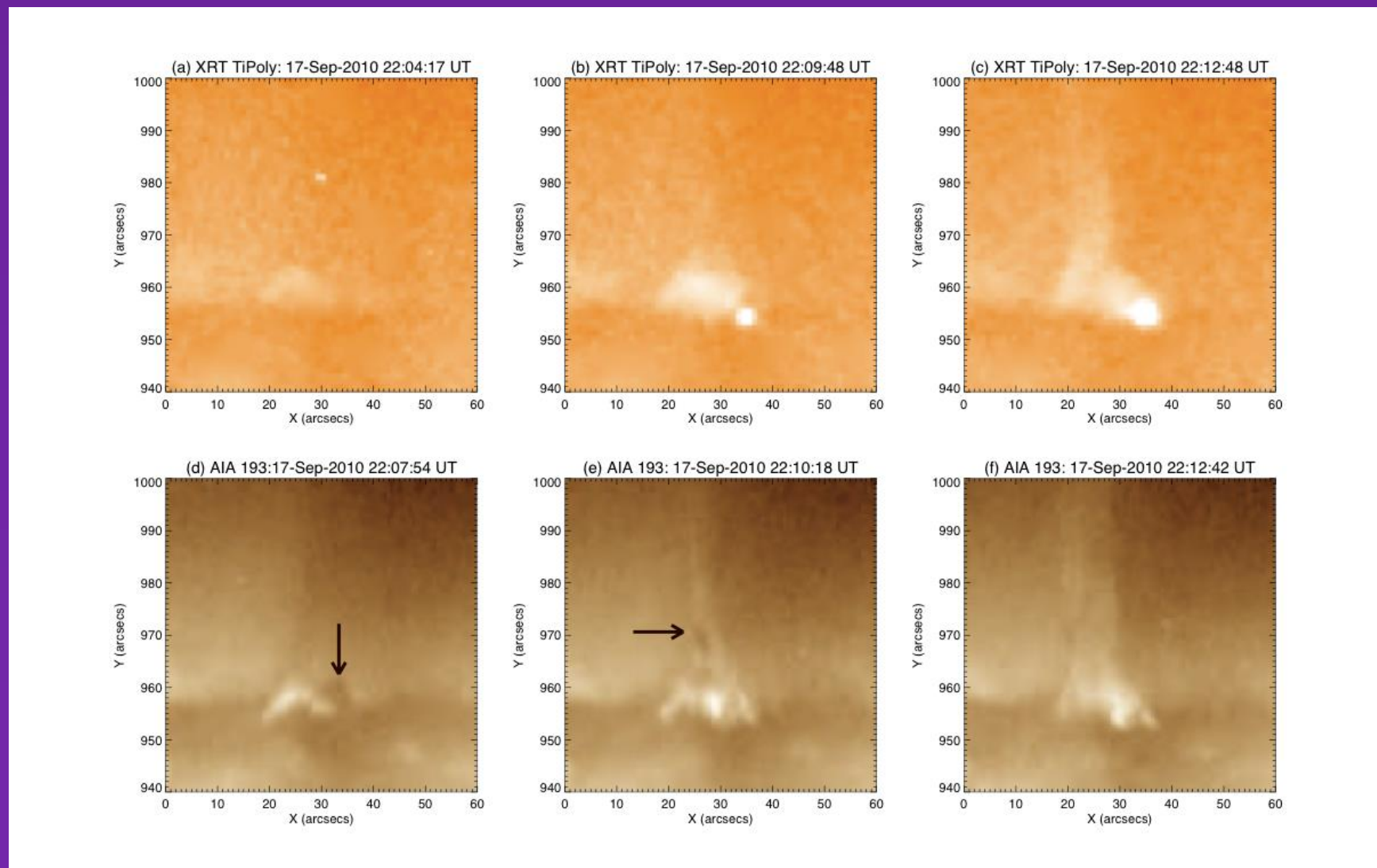
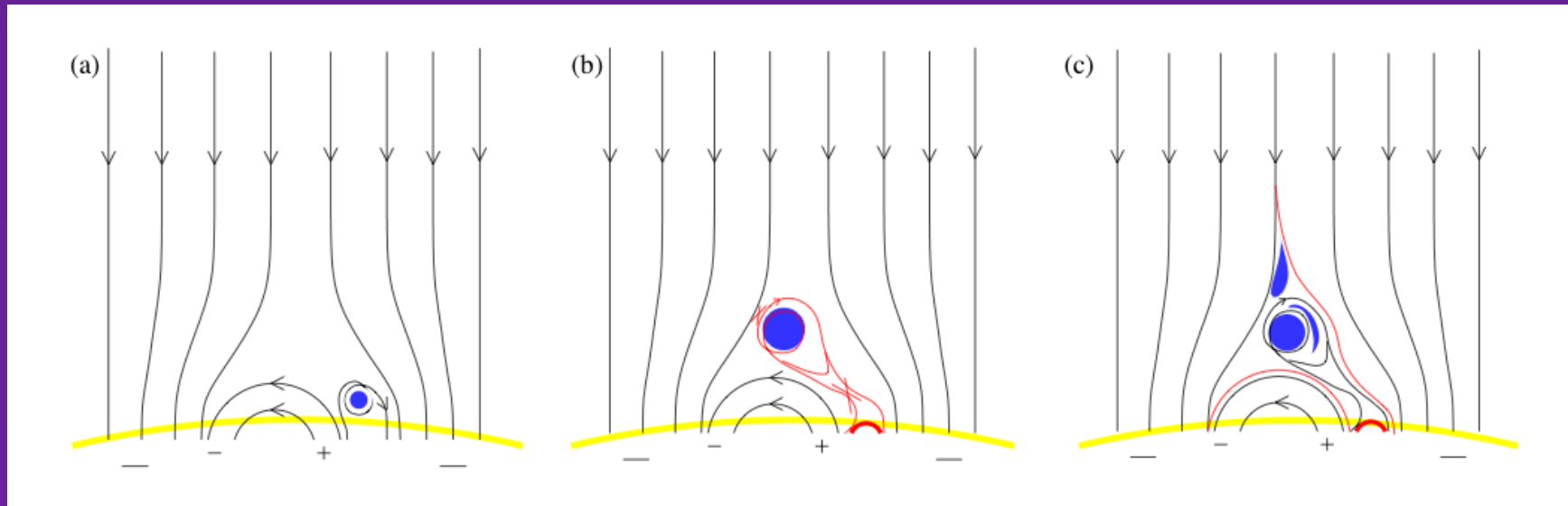
AIA 304



Event 7

- All 20 events show filament material ejected from location that brightens.
- “Standard” ejections (based on morphology) are sometimes fainter and harder to see than in “blowout” cases. Seem to be confined or near-confined eruptions.
- Average (over 18 cases) miniature-filament properties:
 - ♦ Length $\sim(8\pm3)\times10^3$ km.
(cf. “normal” filaments: $3\times10^4\sim1.1\times10^5$ km; Bernasconi et al. 2005)
 - ♦ Pre-ejection $\langle\text{velocity}\rangle = 31\pm15$ km/s.

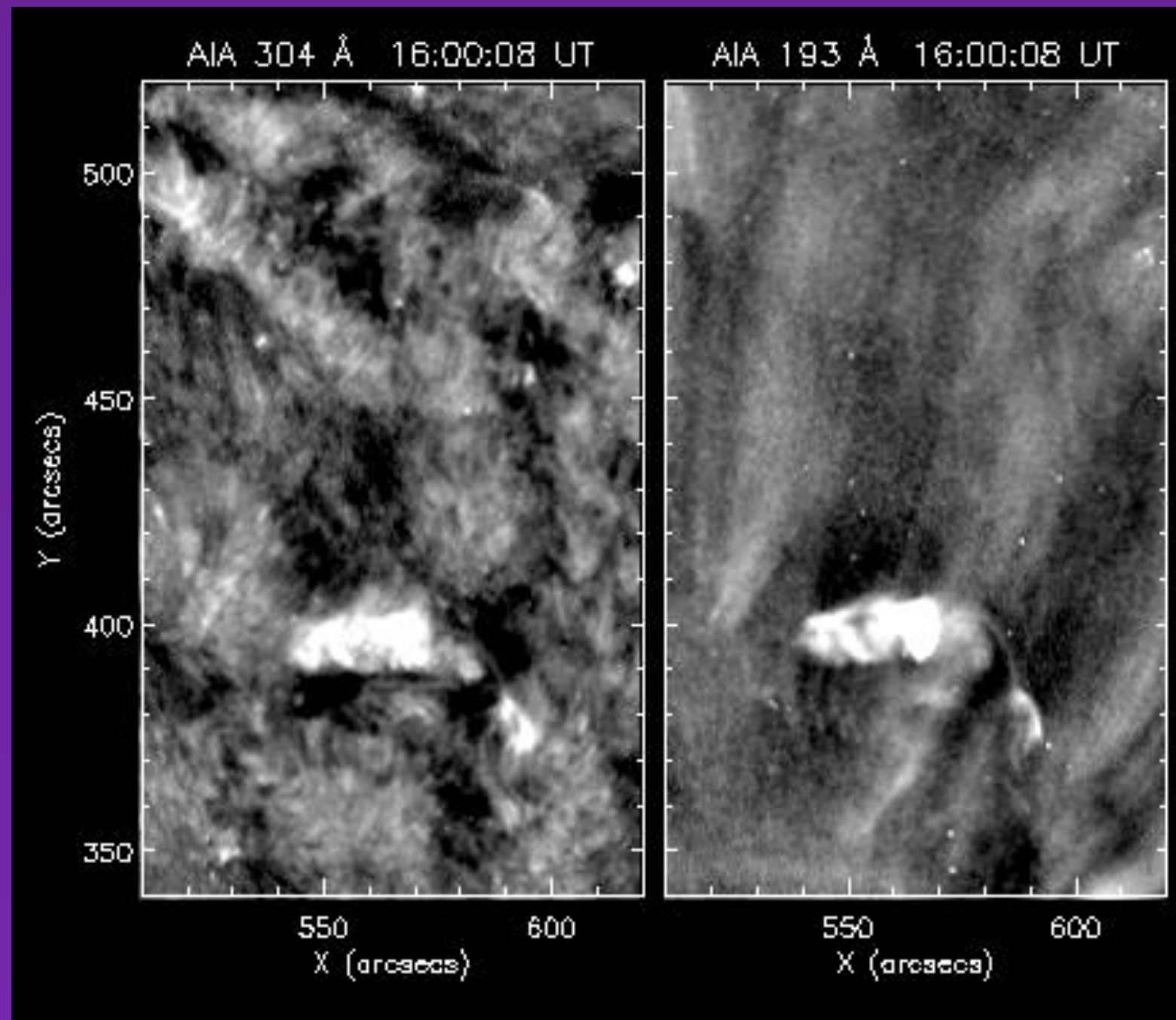
Revised View of X-Ray Jet Formation



How About On-Disk Jets?

- ♦ Not done in this study, but...
- ♦ Adams et al. (2014); above. Basic picture consistent with miniature filament eruption, with “flare” as the jet base brightening.
- ♦ Miniature filaments also seen by others, including Shen et al. (2012), Hong et al. (2014). (Also, Wang et al. 2000.)
- ♦ Other indications of eruptions making jets, e.g., Nisticò et al. (2009), Raouafi et al. (2010).

On-Disk Jet



Shen et al. (2012)

What Causes Miniature-Filament Eruptions?

- ♦ Did not look on-disk in this study, due to polar view. But....
- ♦ Adams et al. (2014) found no emerging flux in the jet region. Filament erupted from location where flux canceled.
- ♦ Huang et al. (2012) and Young & Muglach (2014) found jet from location where flux canceled.
- ♦ Some others, e.g., Liu et al. (2011), Shen et al. (2012), and Hong et al. (2012) found jets from location of emerging flux+flux cancelation.

Reconnection and Spire Drift in Coronal Jets

Ron Moore, Alphonse Sterling, David Falconer

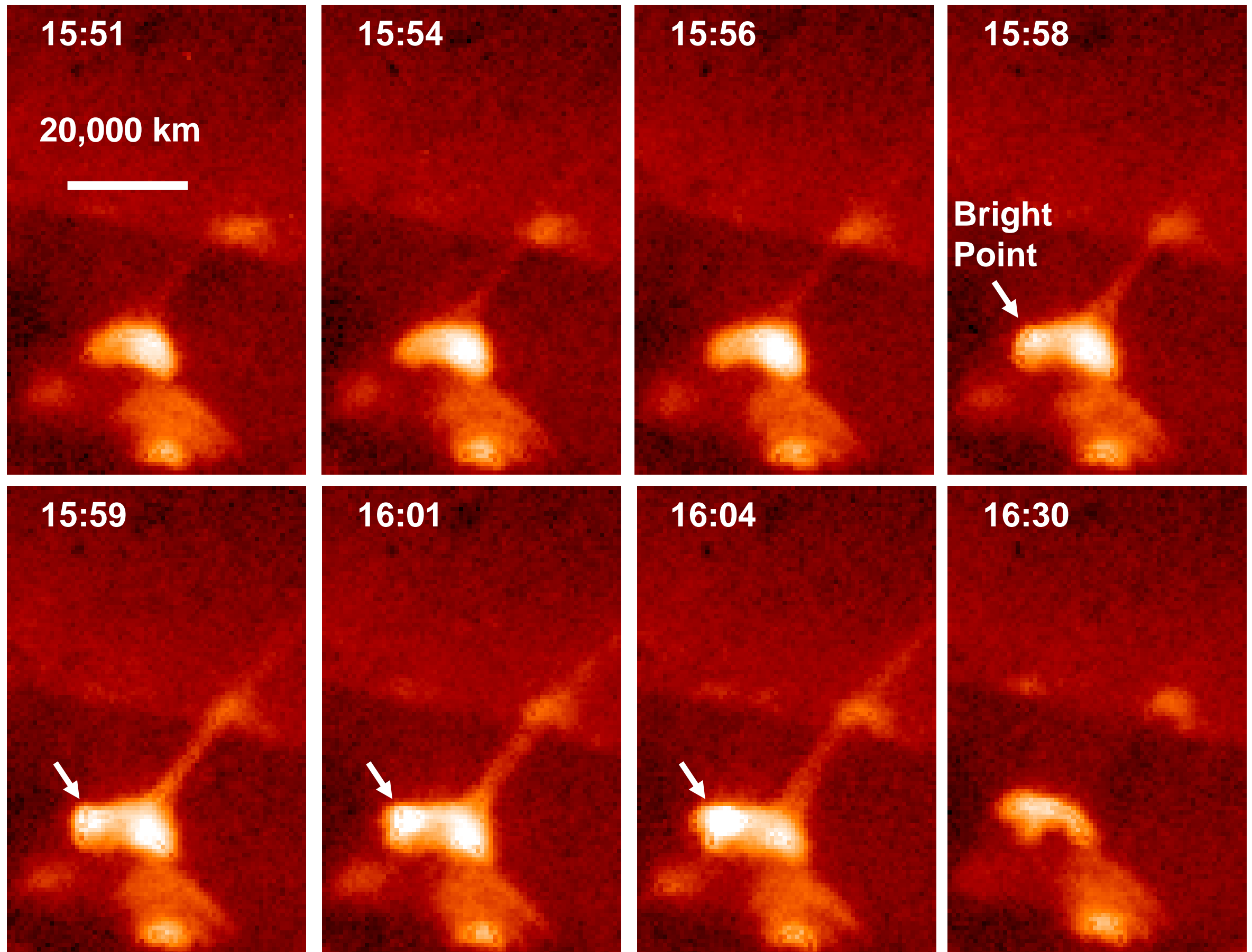
**NASA/MSFC/UAHuntsville
National Space Science and Technology Center**

Main Points

- ☐ There are two kinds of X-ray jets in coronal holes:
standard jets and **blowout** jets.
- ☐ In most jets of either kind, as the spire grows:
 - A bright point grows at the edge of the base of the jet, and
 - The spire drifts away from the bright point. [Cf. Savecheva et al. 2009.]
- ☐ The conventional emerging-flux model for jets implies:
the spire should drift toward the bright point.
- ☐ Alphonse's minifilament-eruption model for jets implies:
the spire should drift away from the bright point.
- ☐ ➡ The observed drift direction is explained by
most coronal-hole X-ray jets being driven by
a minifilament eruption instead of emerging flux.

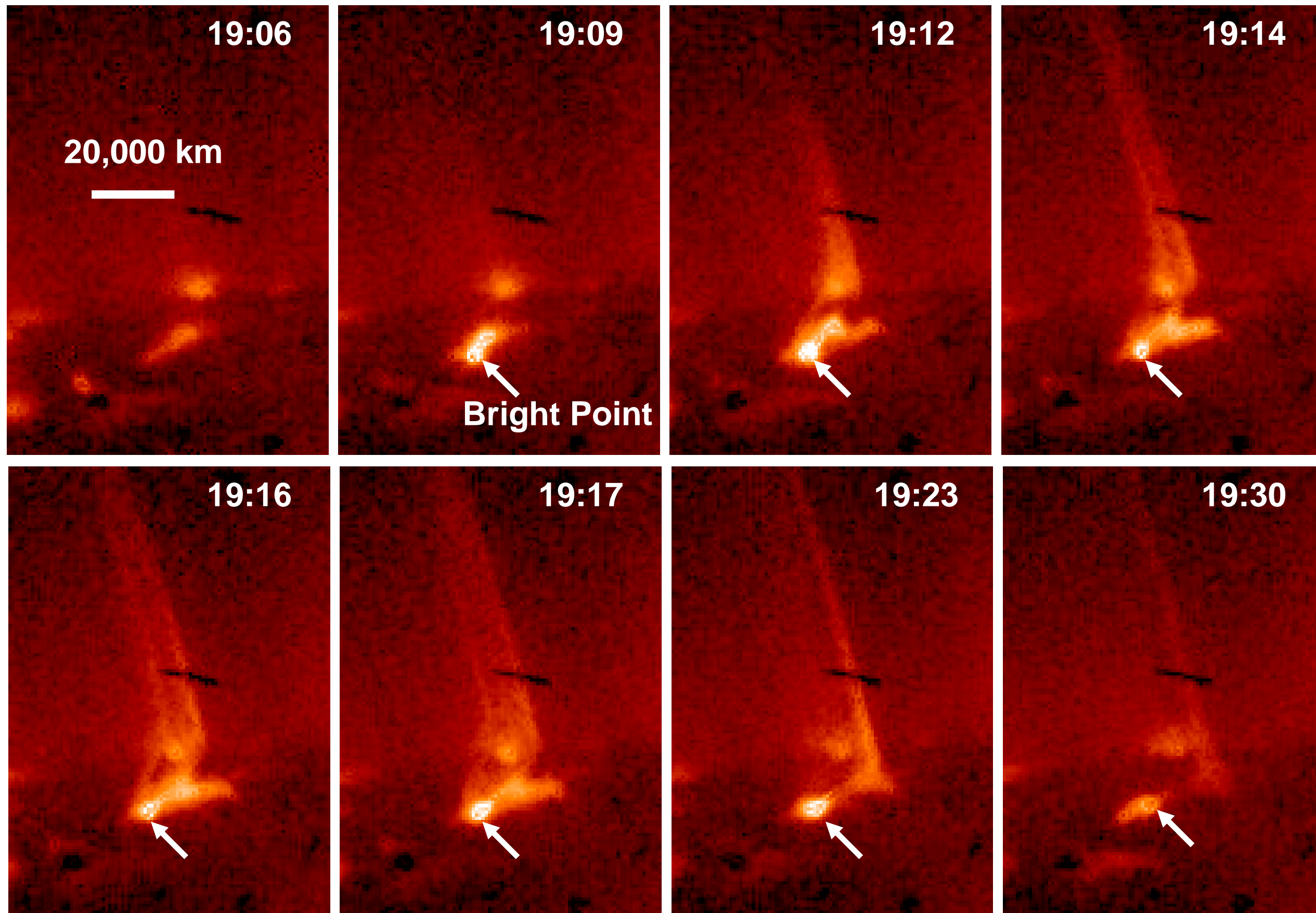
Standard Jet

Hinode/XRT Thin Al Poly, 2008 Oct 5

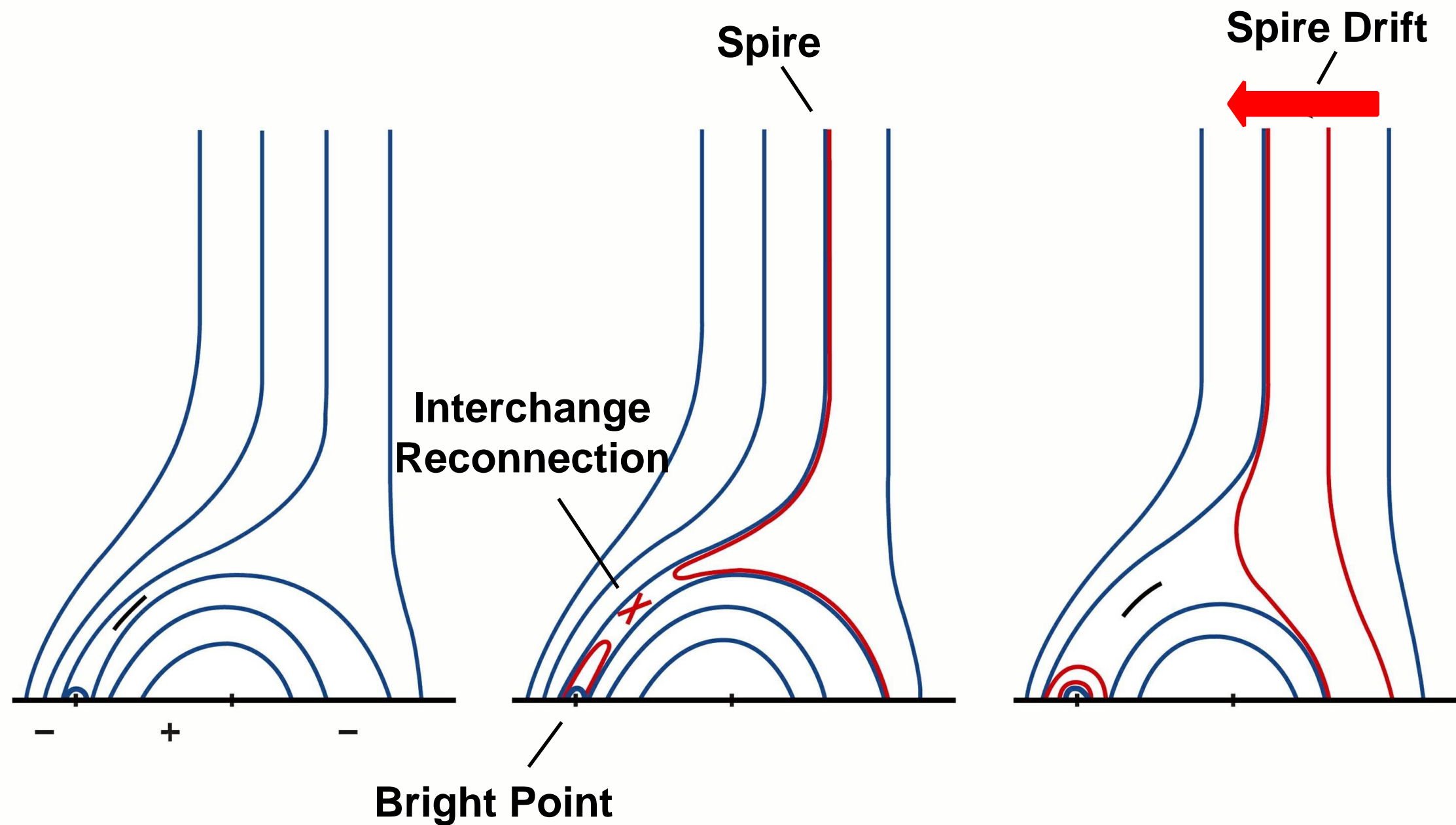


Blowout Jet

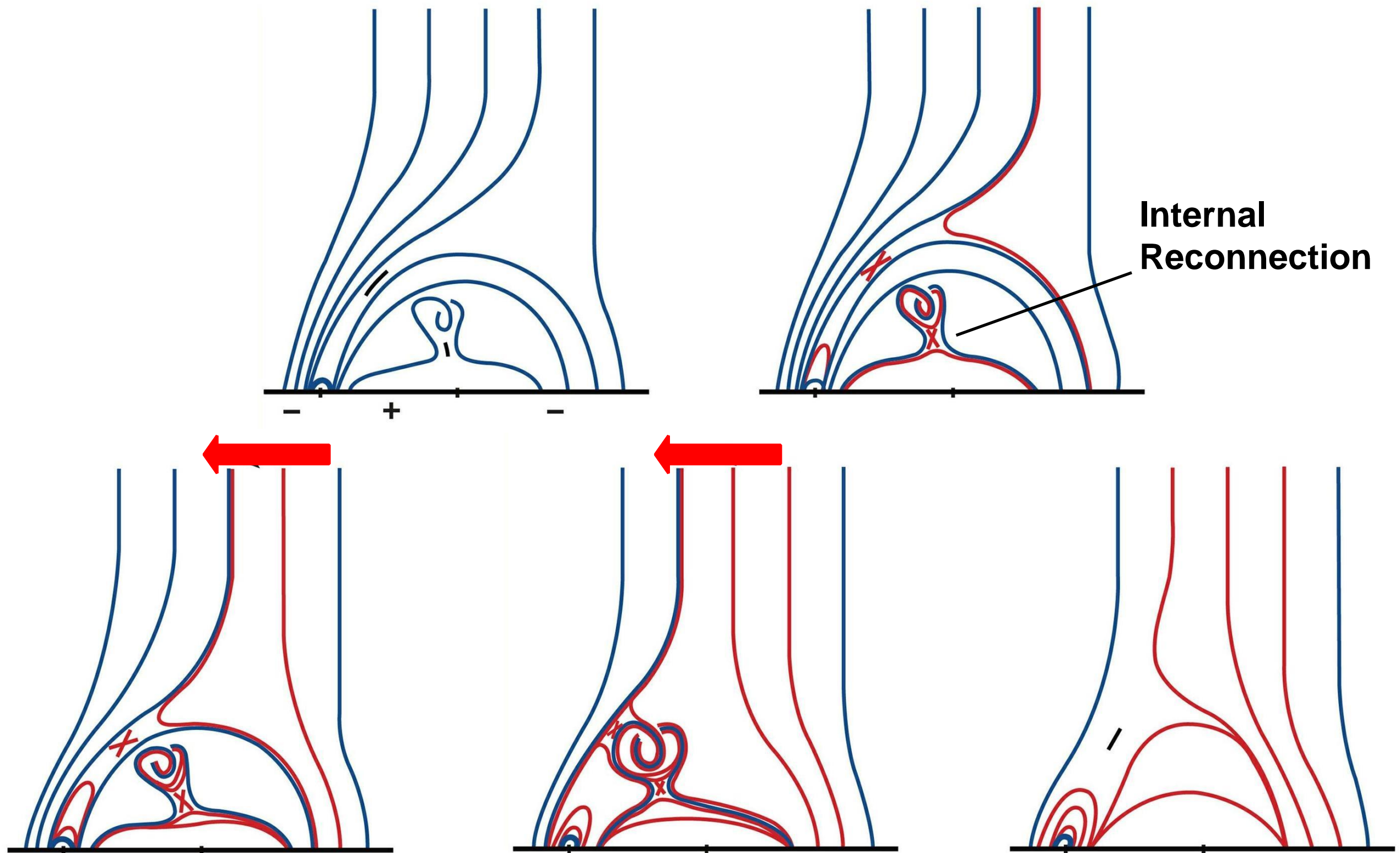
Hinode/XRT Thin Al Poly, 2008 Sept 20



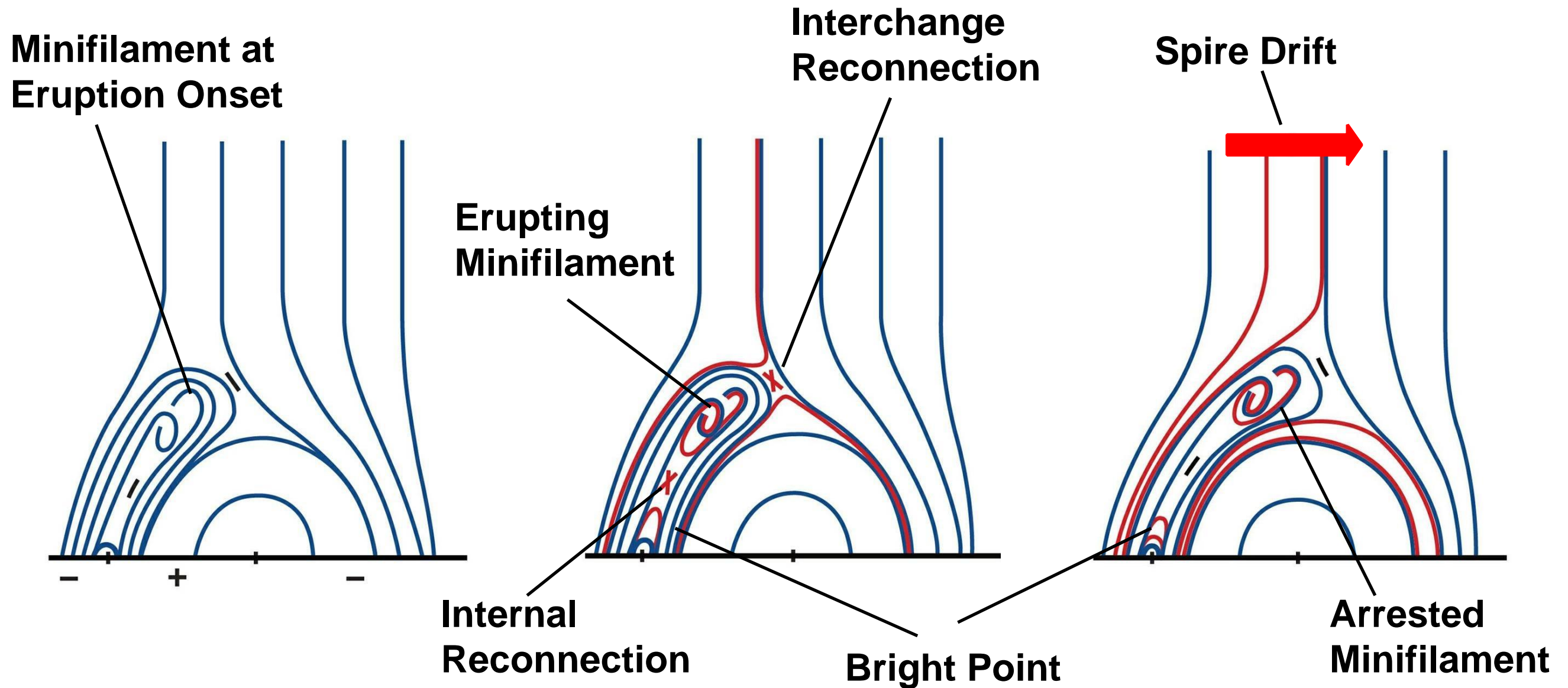
Emerging-Flux Model for Standard Jets



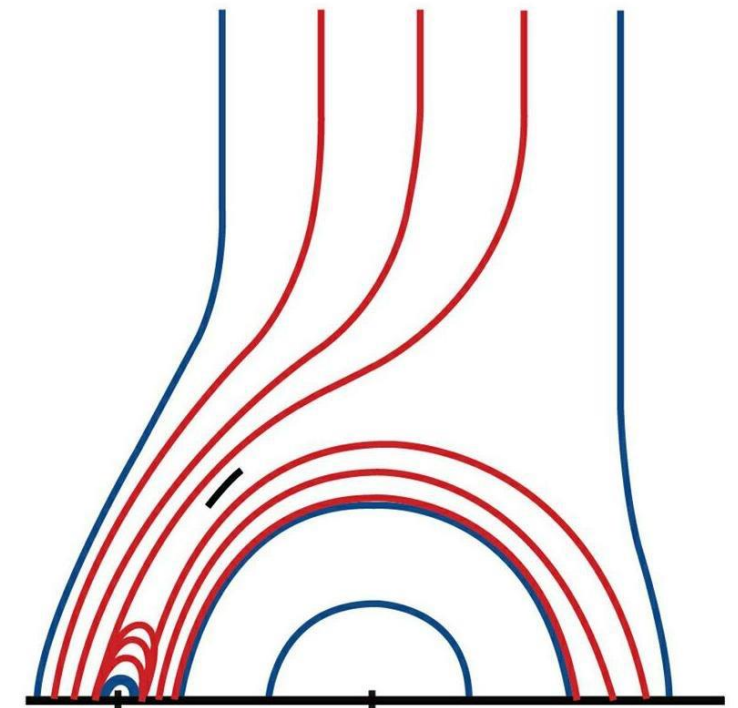
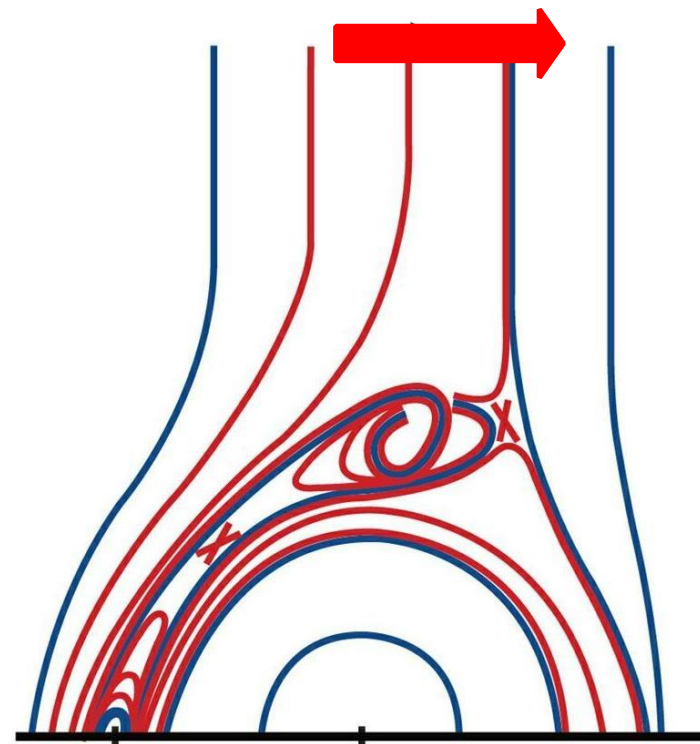
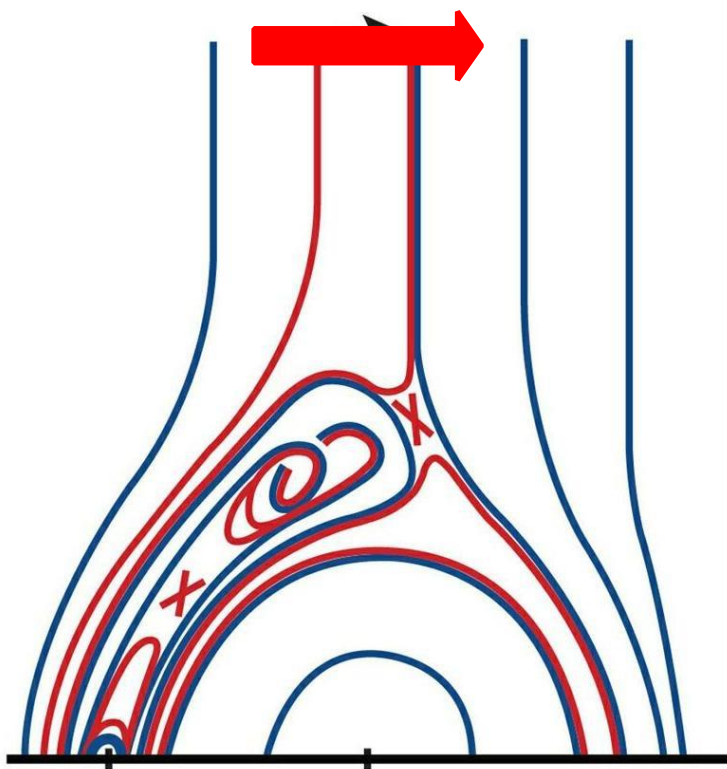
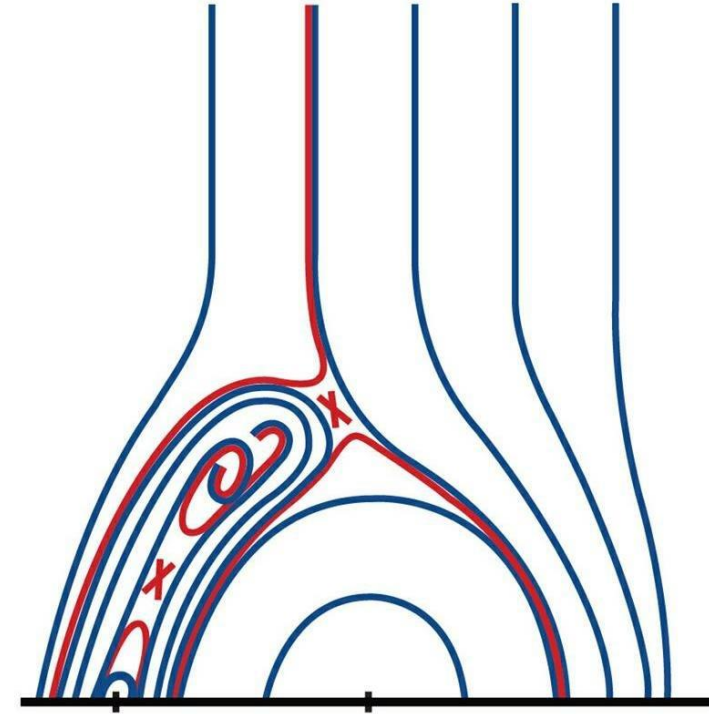
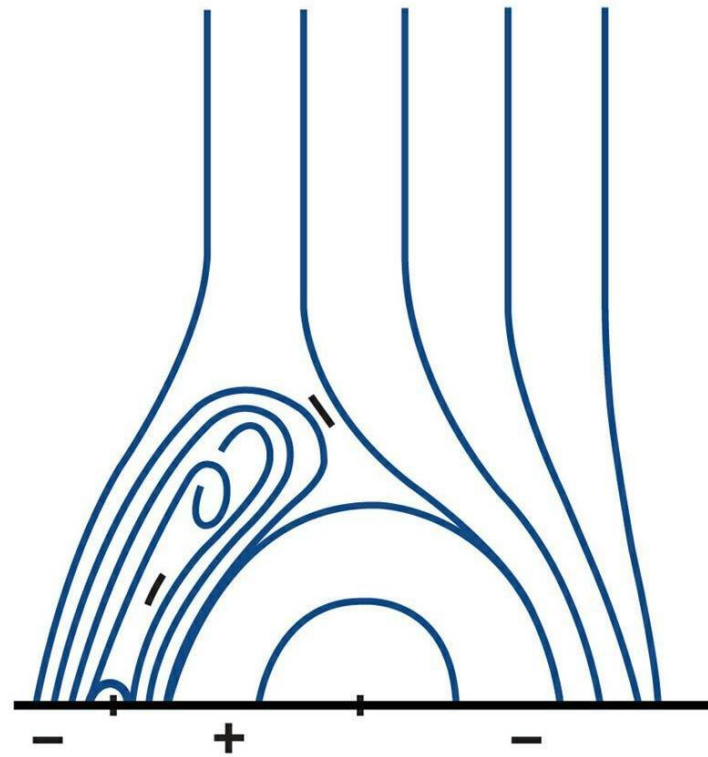
Emerging-Flux Model for Blowout Jets



Minifilament-Eruption Model for Standard Jets



Minifilament-Eruption Model for Blowout Jets



Conclusion

For most X-ray jets in coronal holes,
the spire drift says:

- ☐ **Alphonse's minifilament-eruption model is right.**
- ☐ **The conventional emerging-flux model is wrong.**

Summary

- ♦ We observed 20 polar coronal hole X-ray jets with Hinode/XRT and SDO/AIA.
- ♦ Jets **due to eruptions of miniature filaments**: $\langle \text{length} \rangle \sim (8 \pm 3) \times 10^3 \text{ km}$; pre-ejection $\langle \text{velocity} \rangle = 31 \pm 15 \text{ km/s}$. Consistent with on-disk observations.
- ♦ Look like scaled-down larger-scale filament eruptions, where the jet-base hot-loop brightening corresponds to the flare.
- ♦ Spire drift with time is consistent with mini-filament idea, but not with emerging flux.
- ♦ Roughly speaking, blowout jets correspond to ejective eruptions, and standard jets correspond to confined eruptions.
- ♦ For some on-disk EUV jets, the miniature-filament eruptions result from flux cancelation, but cannot rule out other causes (flux emergences?).
- ♦ Finally: The jet base hot loop is due to internal reconnection, not external reconnection; reconnection at null might not be “sticky.” (\Rightarrow Astrophysical consequences?)